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DYNAMIC VARIABLE AND TEMPORARY INJURY CORRELATION FOR HUMAN HEAD AND NECK IMPACT EXPERIMENTS

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DYNAMIC VARIABLE AND TEMPORARY INJURY CORRELATION FOR HUMAN HEAD AND NECK IMPACT EXPERIMENTS

BRIAN W. WAMSLEY, ALVAH C. BITTNER, JR., NORMAN S. GILBERT, LEONARD S. LUSTICK

ABSTRACT

The Naval Biodynamics Laboratory (NBDL) has collected a data base describing the head/neck kinematic response of a large number of human subject volunteers to -X, +Y, and -X+Y vector exposures. This paper will present injury-related parameters for the most severe exposures in each vector, together with correlations of these parameters with the medical findings. The parameters presented include axial and shear forces and torques at the occipital condyles, as well as the head injury criterion (HIC number). Moderate (R = .35 and .38) but highly siginificant ($p<.025$) correlations were revealed between general (GENFAC) and muscle (MUSFAC) symptom factor variables. These findings encourage continued systematic evaluation of the relationship between the observed injury-related (eg. axial and shear) and medical findings.

INTRODUCTION

The Naval Biodynamics Laboratory (NBDL) has collected a data base describing the head-neck kinematic response of human subject volunteers to -X, +Y, and -X +Y, vector exposures. The goal of this program has been to develop human dynamic and injury response models to impact acceleration as well as to determine the correlation of dynamic responses with physiological effects and injuries. This information is in use for design, construction, and validation of manikins and mathematical models. These products are used to evaluate human protective systems for prevention of casualties from severe impacts (e.g., aircraft crashes and ejections). Thomas, Ewing, Majewski,and Gilbert (1) have previously reported modest correlation between clinical medical effects and sled acceleration and direction. Interestingly, current as well as previous modeling efforts predict that such correlations would be greater, if correlations were made relating "injury-related variables" (eg., maximum shear) with clinical variables (eg., Ewing et al. (2) and Muzzy et al. (3)). This paper will present injury-related parameters for maximum -X,+Y, and -X+Y exposures and their correlations with medical findings .

METHOD

<u>Subjects</u>--The subjects were six Navy enlisted men (ages 19 to 23) who had volunteered for duty as biodynamics research subjects (ie.,subjects H131 to H136). They had been selected to be unusually free of skeletal, cardiopulmonary and other medical or psychological conditions which would preclude participation in potentially hazardous environmental research. The subjects were otherwise typical of the general enlisted population. All subjects were recruited, evaluated, and employed in accordance with SECNAV Instruction Series 3900.39 .and MANMED Instruction Series 3900.6.

These instructions are based upon informed voluntary consent and meet the provisions of prevailing national and international guidelines regarding proper human experimentation. A more detailed description of the volunteers and their selection is given by Thomas, Majewski, Ewing, and Gilbert (4). Tables 1 and 2 respectively contain selected measured and estimated anthropometric parameters for the volunteer subjects.

Tables 1 and 2 about here

Experimental Design -- Subjects were exposed sequentially to blocks of G(-x), G(+y) and G(-x+y) sled profiles with respective maximums of 15, 7 and 9Gs. To minimize the effects of initial conditions each subject was always run in the neck-up, chin-up condition which is standard at NBDL (Ewing et al. (5)). Subjects were medically examined by a physician immediately prior to, shortly after, and 24 hours postrun (or until the abatement of any significant medical findings). This information was recorded for later computer analysis. Retrospective review of the post run medical log yielded five categories of symptoms and physical findings in keeping with that reported by Ewing et al (2). These were (1) hours of muscle soreness; (2) hours of muscle stiffness; (3) hours of headache; (4) hours of backache, and (5) other.

Apparatus -- A Bendix Hyge(R) pneumatically driven .3048m diameter accelerator was used to accelerate an approximately 1.2m by 3.7m multivectorial sled which was rail mounted on Delrin AF(R) pucks. The acceleration stroke is limited to 1.52m and sled mounted brakes were not used. The effective drag is about .2G and the sled was allowed to coast to a stop. Total rail length available is 213m. The impact direction (-X,+Y or -X+Y) was determined by rotation of the multivectorial sled.

The subjects were restrained in a nominally upright position by shoulder straps, a lap belt and an inverted "V" pelvic strap tied to the lap belt. Upper arm and wrist restraints were used to prevent flailing. Figure 1 illustrates the basic restraint system which was used for the three vector directions.

Figure 1 about here

Experimental Measurements -- The dynamic variables presented in this paper were derived by integrated accelerometer and cinephotographic measurement systems (Seemann and Lustick, (6). The accelerometer system yielded measurements using nine piezoresistive accelerometers mounted on a "T" shaped plate at the mouth and six accelerometers mounted on a T-plate at the spinous process of the first thoracic vertebral body (T(1)). The configuration of the accelerometers on the T-plate and the error propogations associated with this method for determining linear displacement, velocity, acceleration and angular orientation, angular velocity and angular acceleration components of a rigid body have been described (Becker and Willems, (7)). The cinephotographic system with the accelerometer system has been previously described (Becker, (8)).

In order to compare subjects at similar points in the anatomy, it is required to define a head anatomical coordinate system and a T(1) anatomical coordinate system (Thomas, (9)). These anthropometric coordinate systems are related to the instrumentation coordinate systems by three-dimensional x-ray anthropometry on each subject (Ewing et al. (5)).

One reference frame for the entire series of experiments is fixed to the laboratory. This is established by first defining a sled coordinate system in which the origin is a benchmark permanently machined into the sled structure. The +X axis is parallel but in the opposite direction to the thrust vector of the accelerator. The +Z axis is parallel to gravity and positive upward and the +Y axis is established so that the axes form an othogonal, right-hand system. A second frame of reference is fixed to the anatomical axes of the head as illustrated in figure 2. (cf. Thomas, (9) for more detail). Both coordinate systems used in this study are right handed where X, Y, and Z axes are taken in that order.

Figure 2 about here

Injury-related variables which will be tabularly reported for all runs include maximum and minimum:

- Linear force components (relative to head X, Y, and Z) over a sled run at the head-neck junction (condyles).

- Torque components (around the head X, Y, and Z) and resultant forces at the head-neck junction.

- HIC component and resultant value for window widths of less than 200 ms.

In addition, plots comparing the time course for these variables for the subjects with the greatest and smallest head mass parameter (H132 and H135) will be provided for illustration of the range of responses. Time courses for these and other selected variables will be graphically provided for a typical subject (H134). Only linear and torque force components will be related to the medical log symptoms by correlational analysis

RESULTS

Evaluation of the data was conducted in three phases. During the first phase, dynamic variables believed to be injury-related were examined. Medical variables were analyzed during the second phase. The third phase was concerned with correlation of the injury-related variables and medical variables.

Injury-Related Variables.

Injury-related dynamic variables were tabulated and graphically analyzed during this phase of evaluation. Graphical analysis revealed, as might be expected that the injury-related variables tended to increase in magnitude with increasing exposure (G) levels for the three vector directions. Figures 3, 4, and 5 illustrate time courses for respective changes in the resultant force, resultant torque and HIC variables for a range of 10.2 to 15.6 G(-X), 5.3 to 7.0(+Y), and 9.3 to 11.4(-X+Y). It should be pointed out that, occasionally, experienced forces may be substantially greater for a relatively lower sled G level than at higher levels for the same subject (e.g., H132 at 13 vs. 15 G(-x) in Appendix A). The trend toward increasing injury-related magnitudes with increased exposure limits focused our attention toward the higher levels in later analyses.

Figures 3, 4, and 5 about here

Graphical analyses also indicated that individual differences play a role in experienced forces under nominally the same sled force conditions. Figures 6, 7, and 8 show shear and axial forces as well as resultant torque time-courses for subjects with greatest (H135) and least (H132) head mass parameters. Over nominal 15G(-x), 7G(+y) and 10G(-x+y) conditions, the largest headed subject (H132) tended to experience greater stresses than the smallest subject. The larger subject, as will be seen later, also reported greater medical problems post-run. The apparent role of individual differences focused our attention on their importance in later analyses.

Figures 6, 7, and 8 about here

The results of graphical analysis suggested tabulating experienced injury-related variables for the greatest experienced level for each vector and each subject. The appendix contains a portion of this tabulation.

Medical Variables

The medical variables were tabulated and analyzed during the second phase of evaluation. Table 3 provides the basic data by subject and run. Examining this table, it may be noted that some runs were uneventful while other runs resulted in clusters of symptoms (muscle soreness and muscle stiffness tend to go together). It may also be seen that about 30 percent of the impact runs resulted in some significant symptom. The nature and frequency of such findings were similar to that reported by Thomas et al. (1) where significant symptoms were reported for about 40 percent of the runs. This clustering of symptoms suggested condensing the symptoms into "factors" which are more syndrome in character.

Table 3 about here.

A principal factor analysis was conducted on transformations of the variables shown in Table 3. The first four variables (hours of muscle soreness, through hours of backache) were transformed (log(x)+1) to reduce skewness and theoretically enhance linearity. The last variable was coded as "0" or "1" to respectively denote the absence or presence of other symptoms. The transformed variables are subsequently labeled MUSOR, MUSIF, HEAD, BACK, and OTHER for purposes of identification. The analysis resulted in evidence of a strong first factor (syndrome) which accounted for 50.8% of the variance across the symptoms (eigen-value of 2.53). A second factor (syndrome) was also suggested which added an additional 25.4% of the variance (eigen-value of 1.27). For purposes of this investigation, it was decided to consider results for both the one and two factor solutions with the injury-related variables. Table 4 provides the intercorrelation of the medical variables as well as their loadings (correlations) on the derived factors.

TABLE 4 about here.

The factor from the first solution we termed GENALFAC. Those from the second were respectively termed MUSFAC and OTHRFACT. These terms were selected to reflect the relative prominence of general, muscular, and other symptom loadings on the respective factors (cf, Table 4).

Correlation of Medical and Injury-Related Variables

Stepwise regression analysis was applied to each of the three medical factor variables (i.e., GENFAC, MUSFAC and OTHRFAC). Interestingly, prior to the analyses, it had been planned to force specific variables (Maximum Shear, and absolute Axial Forces); however, these were selected from GENFAC and MUSFAC by the stepwise procedure. We also correlated G-level with these factor variables, but maximum shear or axial force showed a higher correlation. For OTHRFAC, the Shear and Axial Variables were unpredictive and a broad range of other variables were condidered (e.g. Torques at the condyles, etc.). Analyses for GENFAC and MUSFAC represent planned analyses while that for OTHRF was exploratory.

GENFAC.

Regression analysis with the shear and axial variables yielded a significant multiple $\underline{R} = 0.354$ ($F(2,57) = 4.07$, $p<.025$). The prediction equation is :

$$GENFAC = -.7194+.0027Z+.0028S \qquad (1)$$

where Z is the greatest negative axial force (Newtons) and S is the maximum shear (Newtons). The coefficient for Z and S significantly exceeded their respective standard errors ($F(1,57) = 5.20$, $p<.05$ and $F(1,57) = 7.83$, $p<.01$). Equation (1) predicts an increasing GENFAC with increasing sheer force and lessening of the axial force which tends to hold the head on the neck.

MUSFAC. Regression analysis with the axial and sheer variables yielded a significant multiple R = 0.378 ($F(2,57) = 4.75$, $p<.012$). The prediction equation is:

$$MUSFAC = -.8435 + .0025Z + .0029S \qquad (2)$$

where Z and S are as defined for equation (1). Again the coefficient for Z and S significantly exceed their respective standard errors ($F(1,57) = 4.44$, $p<.05$ and $F(1,57) = 8.26$, $p<.01$). Equation (2) predicts increases in MUSFAC under conditions similar to that of (1).

OTHRFAC

Initial regression analysis with axial and shear forces yielded no results of consequence. Subsequent stepwise analysis was only relatively more productive; the best single predictor was the maximum torque about the X-axis ($R = .18$, $p>.16$) which even in conjuction with a second predictor (greatest negative torque about the S-axis) yielded no improvement ($R = 0.236$, $p>.19$). The resulting OTHRFAC prediction equation weight for the torque variables were in the direction of increasing with increasing torque magnitude.

DISCUSSION

This report considered the relationship between variables believed to be injury-related and their correlation with medical findings over (-X), (+Y) and (-X+Y) impacts. Initial analyses focused upon relationships within the medical variables. These focused our attention on the relationship between the injury-related and medical factor variables. Our discussion of these results will follow this pattern of analysis and will precede conclusions.

Injury-Related Variables.

The graphical analyses of these variables revealed two relationships. First and not unexpectedly, the injury-related variables tended to increase with the nominal magnitudes for each vector direction exposure (cf, Figure 3, 4 and 5). This focused attention on the nominally most severe runs for each vector direction in the NBDL database.

The second finding of the graphical analyses was the apparent relationship between the injury-related criteria and anthropometery (i.e., head mass) seen in Figures 6, 7 and 8. Subject H132 with the largest head mass experienced larger forces and torques than the smallest (H135). These subjects also differed on other variables in a similar pattern (e.g. neck length) and consequently the observed systemic differences can not be uniquely ascribed to head mass. (However, the report by Muzzy et al. (3) certainly indicates a strong relationship between head mass and resultant forces and torques.) Interestingly subject H134, with an intermediate head mass reported no adverse effects and had a particuarly short neck.

Currently, we are initiating correleration of variables across subjects in an effort to be more definitive. Certainly, these results point to consistent individual differences which are embedded in our later analyses.

Medical Findings

Summary of the medical findings revealed apparent clusters of reported symptoms (cf, Table 3). These clusters could reflect: subject tendencies to complain; subject differences in "injury"; or a combination of both. The tendency for subject H132 (largest head mass) to report more often than H135 (smallest) did give some initial support for the view that actual injury differences are involved.Factor analysis was performed to identify and condense the symptoms prior to correlation analyses with the injury-related variables. Table 4 standarized the correlation between the transformed medical variables and factors which resulted from this analysis.

Regression Analyses

The correlational analyses relating the medical factors and injury-related variables provided strong evidence of their relationship. Both the GENFAC (general) and the MUSFAC (muscle) factor variables exhibited moderate but highly significant ($p<.025$ and .012 respectively) correlation with the same sheer and axial forces experienced by the subject ($r = .35$ and .38). The prediction equations for these two variables were also similar equation (cf,equations (1) and (2)). These similarities, were in part not unexpected as GENFAC may theoretically be viewed as a comparison between MUSFAC and OTHRFAC. However, the correlation bewteen MUSFAC and GENFAC was relatively higher than expected ($r = .86$). In any case, the relationship between the injury-related dynamic variables and the medical reports is supported by the results in the paper. The choice of symptom cluster does remain open for future work.

CONCLUSION

The findings of this report encourage continued systematic evaluation of the relationship between observed injury-related variables and medical findings. Certainly, the results of this report indicate a moderate but highly significant correlation between reported symptoms and the maximum shear and greatest negative axial forces. Based on this report, additional correlation analyses relating individual differences in anthropometeric variables (head and neck size) with the injury-related and medical variables appears a fruitful direction for future work. Perhaps equally productive might be correlation of such variables and injuries experienced by civilian and military personnel in impact environments. We encourage other researchers to focus on non-permanent symptoms following impacts and their relationship with subject variables.

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Table 1. Subject Anthropmetric Variables

Subject	Age (Yrs)	Height (cm)	Weight (kg)	Head Circumference (cm)	Head Length (cm)
H131	20	167.0	67.7	57.5	19.6
H132	21	172.9	80.0	57.9	19.7
H133	20	161.7	61.4	56.1	19.4
H134	20	178.3	75.5	56.6	19.4
H135	23	171.6	69.1	53.5	17.9
H136	19	185.4	89.1	56.4	19.4

Table 2. HEAD MASS PARAMETERS

SUBJECT	MASS* (gm)	CENTER OF MASS** (cm)			PRINCIPAL MOMENTS** OF INERTIAL (Kg-cm(2))		
		X	Y	Z	X'	Y'	Z'
H131	4449	0.84	-.06	3.17	219.8	235.0	152.9
H132	4523	0.84	-.06	3.18	225.9	241.5	157.2
H133	4170	0.82	-.05	3.10	197.3	211.0	137.3
H134	4278	0.83	-.05	3.13	205.9	220.1	143.3
H135	3791	0.80	-.05	3.00	168.3	180.0	117.1
H136	4235	0.83	-.05	3.12	202.4	216.4	140.9

*Mass estimated from head circumference and length (Kaleps et et al., 1984)
**Center of mass and principal moments estimated via isometric analysis (Bittner, 1986)

RUN NUMBER	SUBJECT NUMBER	G level	MUSCULE SORENESS (HOURS)	MUSCLE STIFFNESS (HOURS)	HEADACHE (HOURS)	BACKACHE (HOURS)	OTHE (YES/N
3908	H131	10.2G(-x)					
3948	H131	13.7G(-x)					
3987	H131	14.5G(-x)					
3990	H131	15.4G(-x)					
4089	H131	5.1G(+y)					
4109	H131	6.2G(+y)					
4124	H131	7.2G(+y)					YES*
4242	H131	7.3G(-x+y)					YES*
4251	H131	10.2G(-x+y)					
3989	H132	10.3G(-x)	59	59			
3950	H132	13.6G(-x)	68	68	7		
3957	H132	14.7G(-x)	33	33	4		
3982	H132	15.6G(-x)	49	49			
4090	H132	5.1G(+y)	67	67		67	
4110	H132	6.1G(+y)	70	70			
4128	H132	7.1G(+y)	47				
4261	H132	9.0G(-x+y)					
4297	H132	10.0G(-x+y)					
4306	H132	11.1G(-x+y)	48		33	48	YES*
3998	H133	10.2G(-x)					
3951	H133	13.4G(-x)					
3963	H133	14.5G(-x)					
3986	H133	15.6G(-x)					
4093	H133	5.1G(+y)					
4111	H133	6.1G(+y)					
4125	H133	7.2G(+y)			6		
4236	H133	7.3G(-x+y)	44	44	2		
4240	H133	9.1G(-x+y)	95	95	11		
3993	H134	10.2G(-x)					
3961	H134	13.4G(-x)					
3968	H134	14.3G(-x)					
3983	H134	15.6G(-x)					
4097	H134	5.0G(+y)					
4112	H134	6.1G(+y)					
4126	H134	7.1G(+y)					
4264	H134	9.3G(-x+y)					
4298	H134	10.1G(-x+y)					
4307	H134	11.4G(-x+y)					

* two premature ventricular contractions after impact
** right bundle branch block for three complexes impact
*** felt "stunned" after impact, complained of dizziness for 2 days

RUN NUMBER	SUBJECT NUMBER	G level	MUSCULE SORENESS (HOURS)	MUSCLE STIFFNESS (HOURS)	HEADACHE (HOURS)	BACKACHE (HOURS)	OTHE (YES/N
3916	H135	10.3G(-x)					
3955	H135	13.6G(-x)		18			
3965	H135	14.6G(-x)					
3970	H135	15.6G(-x)					
4095	H135	5.2G(+y)					
4114	H135	6.1G(+y)					
4131	H135	7.3G(+y)	44	44			
4314	H135	9.1G(-x+y)					
4316	H135	10.1G(-x+y)					
4918	H136	10.2G(-x)		20			
3953	H136	13.3G(-x)	33	33			
3962	H136	14.1G(-x)	47	47	47	47	
4098	H136	5.1G(+)					YES*
4142	H136	6.0G(+y)					
4153	H136	7.1G(+y)					
4247	H136	7.1G(-x+y)					
4263	H136	9.2G(-x+y)	240				

**** one premature venticular contraction 22 seconds after impact

TABLE 4. MEDICAL VARIABLE INTERCORRELATIONS AND FACTOR LOADINGS

	MEDICAL VARIABLES					ONE FACTOR SOLUTION FACTOR	TWO FACTOR SOLUTION FACTOR 1	TWO FACTOR SOLUTION FACTOR 2
	MUSOR	MUSIF	HEAD	BACK	OTHER	(GENFAC)	(MUSFAC)	(OTHRFAC)
MUSOR	1.000					.856	.901	.169
MUSIF	.800	1.000				.775	.929	-.032
HEAD	.498	.412	1.000			.797	.549	.629
BACK	.402	.286	.588	1.000		.717	.403	.715
OTHER	.046	-.114	.250	.289	1.000	.232	-.232	.823

Figure 1, Illustration of the Restraint System as implemented on Subject H134.

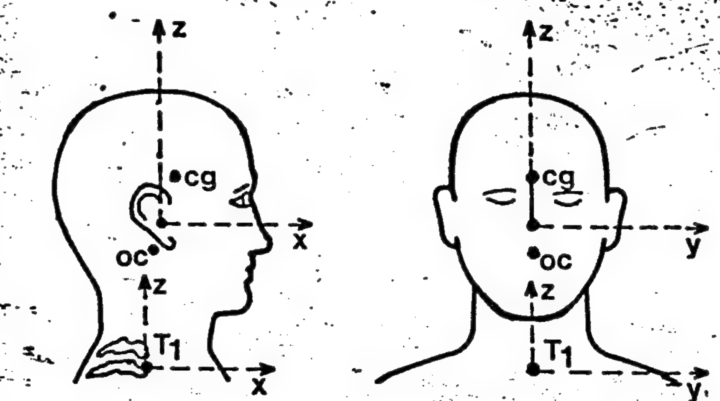


FIGURE 2. HEAD AND T1 ANATOMICAL COORDINATE SYSTEMS

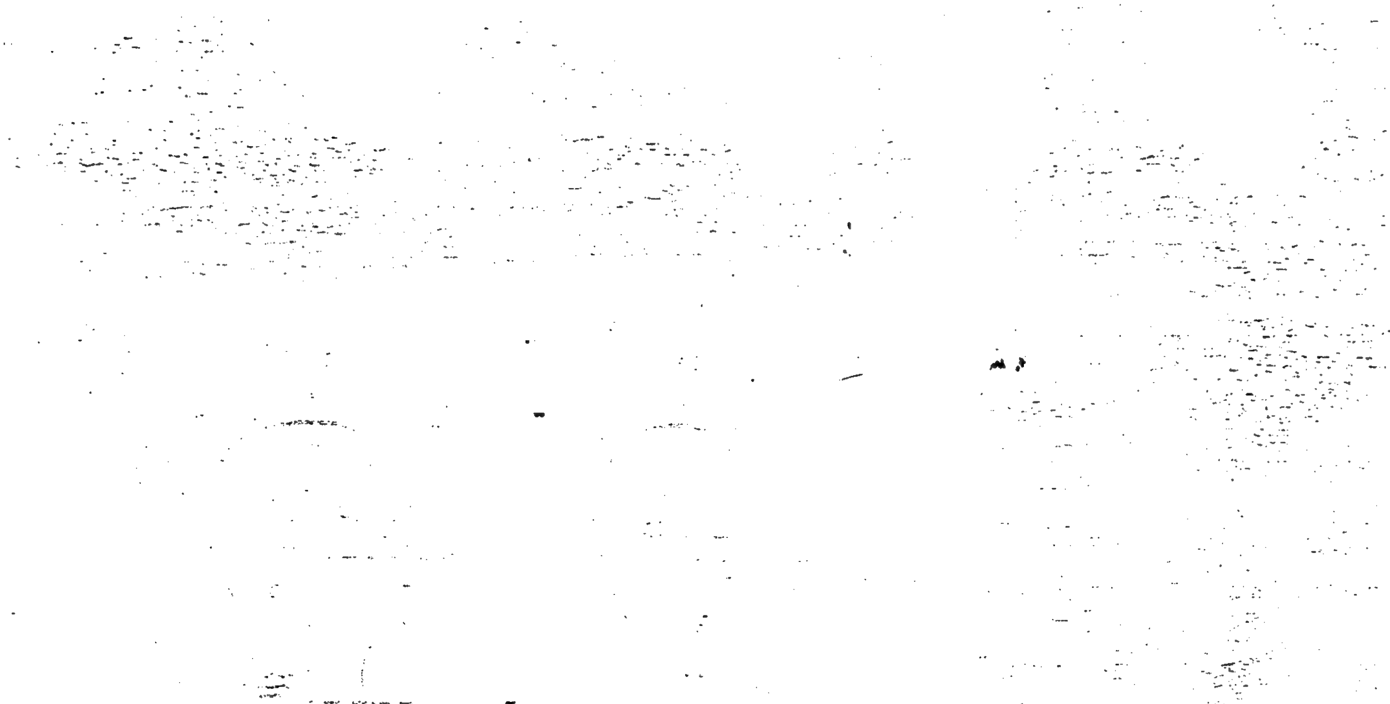


Figure 3. Resultant Force Time-Courses Across -X, +Y, And -X+Y Vector Directions And Selected Accelerations For H134

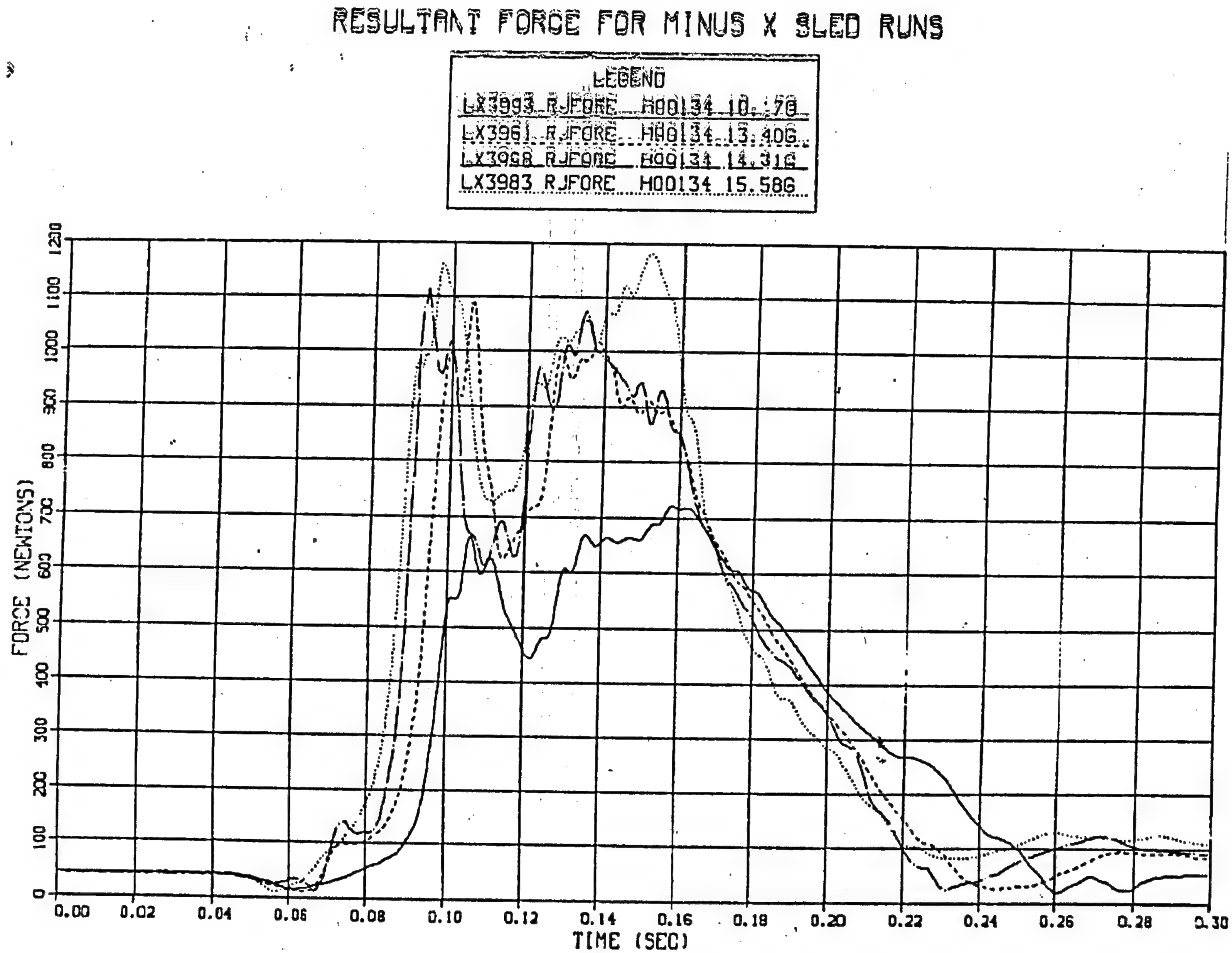

RESULTANT FORCE FOR MINUS X SLED RUNS
LEGEND
LX3993 RJFORE H00134 10.70
LX3961 RJFORE H00134 13.40G
LX3968 RJFORE H00134 14.31G
LX3983 RJFORE H00134 15.58G
FORCE (NEWTONS)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
0.28
0.30
TIME (SEC)

Fig 39

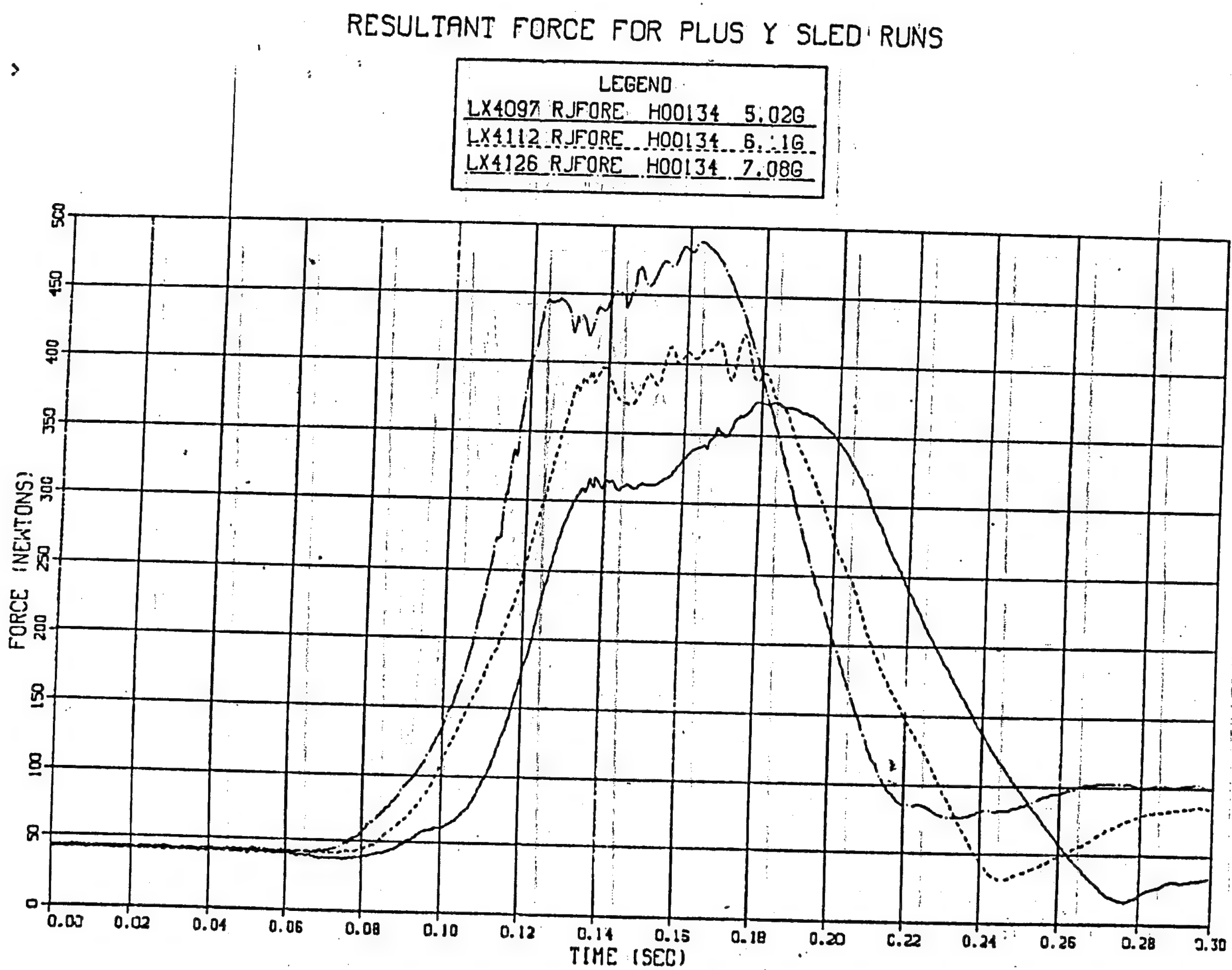

RESULTANT FORCE FOR PLUS Y SLED RUNS
LEGEND
LX4097 RJFORE H00134 5.02G
LX4112 RJFORE H00134 6.11G
LX4126 RJFORE H00134 7.08G
FORCE (NEWTONS)
0
50
100
150
200
250
300
350
400
450
500
TIME (SEC)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
0.28
0.30

Fig 3b

RESULTANT FORCE FOR MINUS X : PLUS Y SLED RUNS

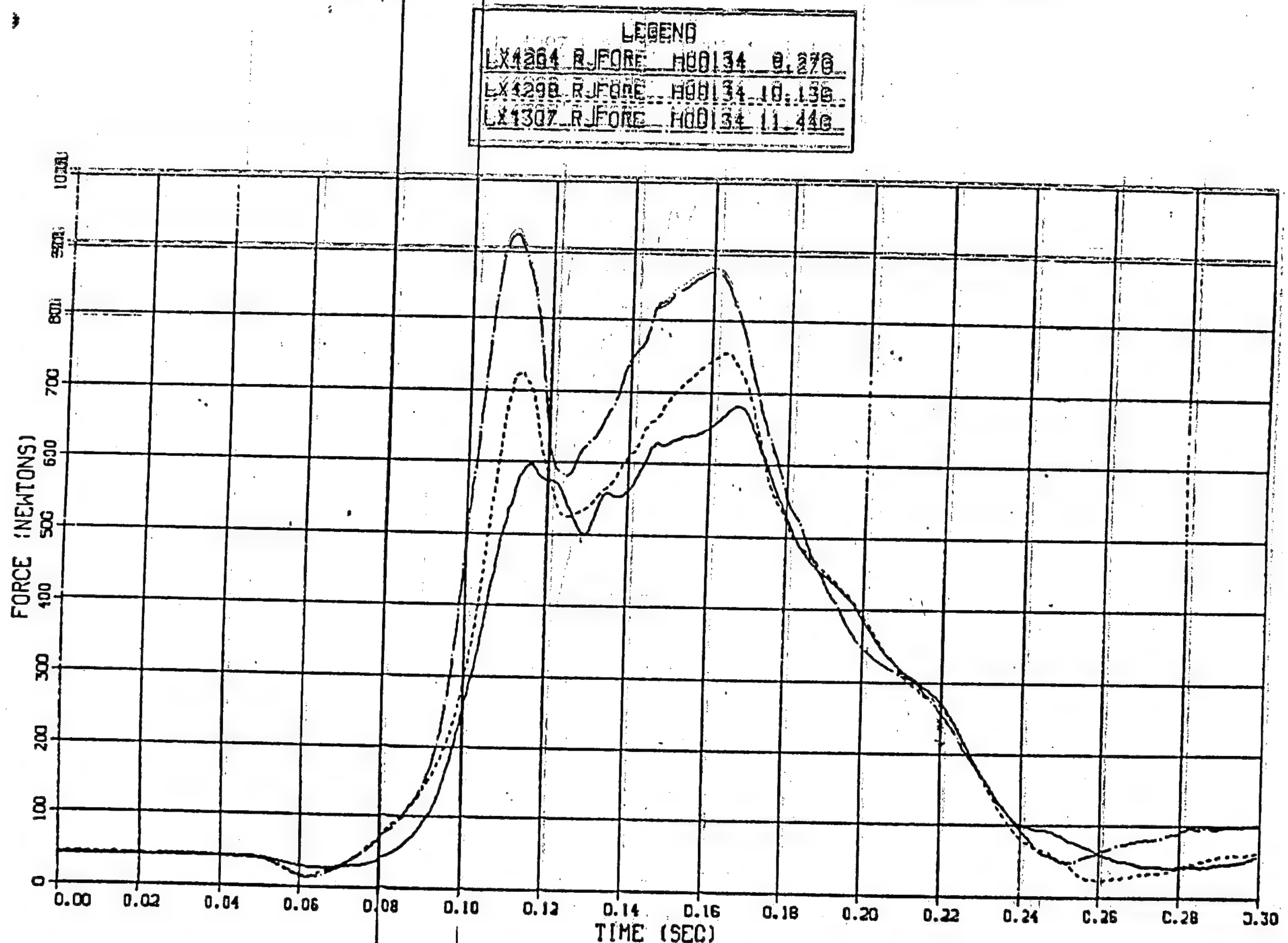


Fig 3C

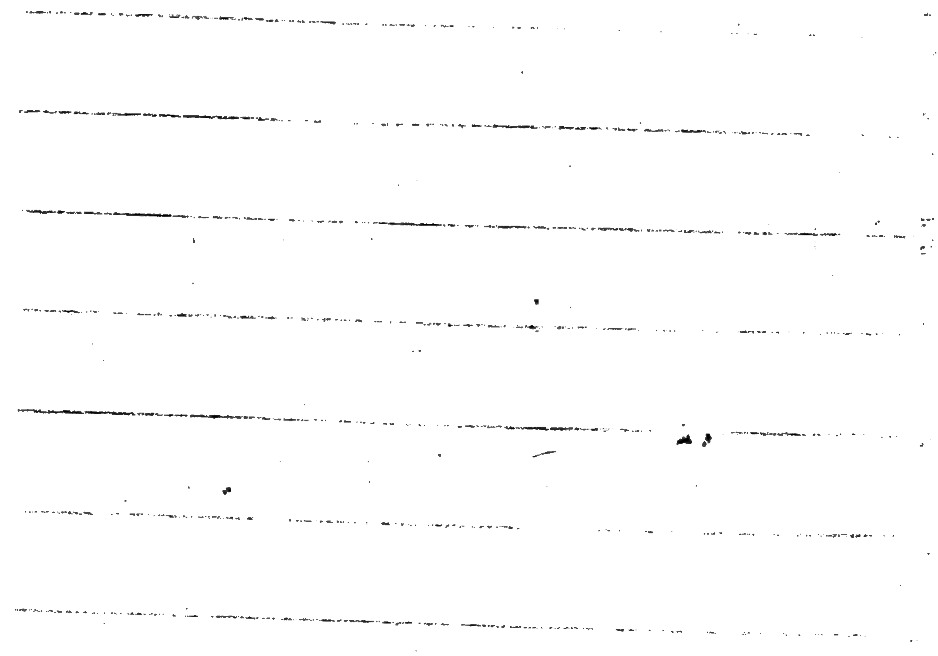


Figure 4. Resultant Torque Time-Courses Across -X, +Y and -X+Y Vector Directions and Selected Accelerations For H134

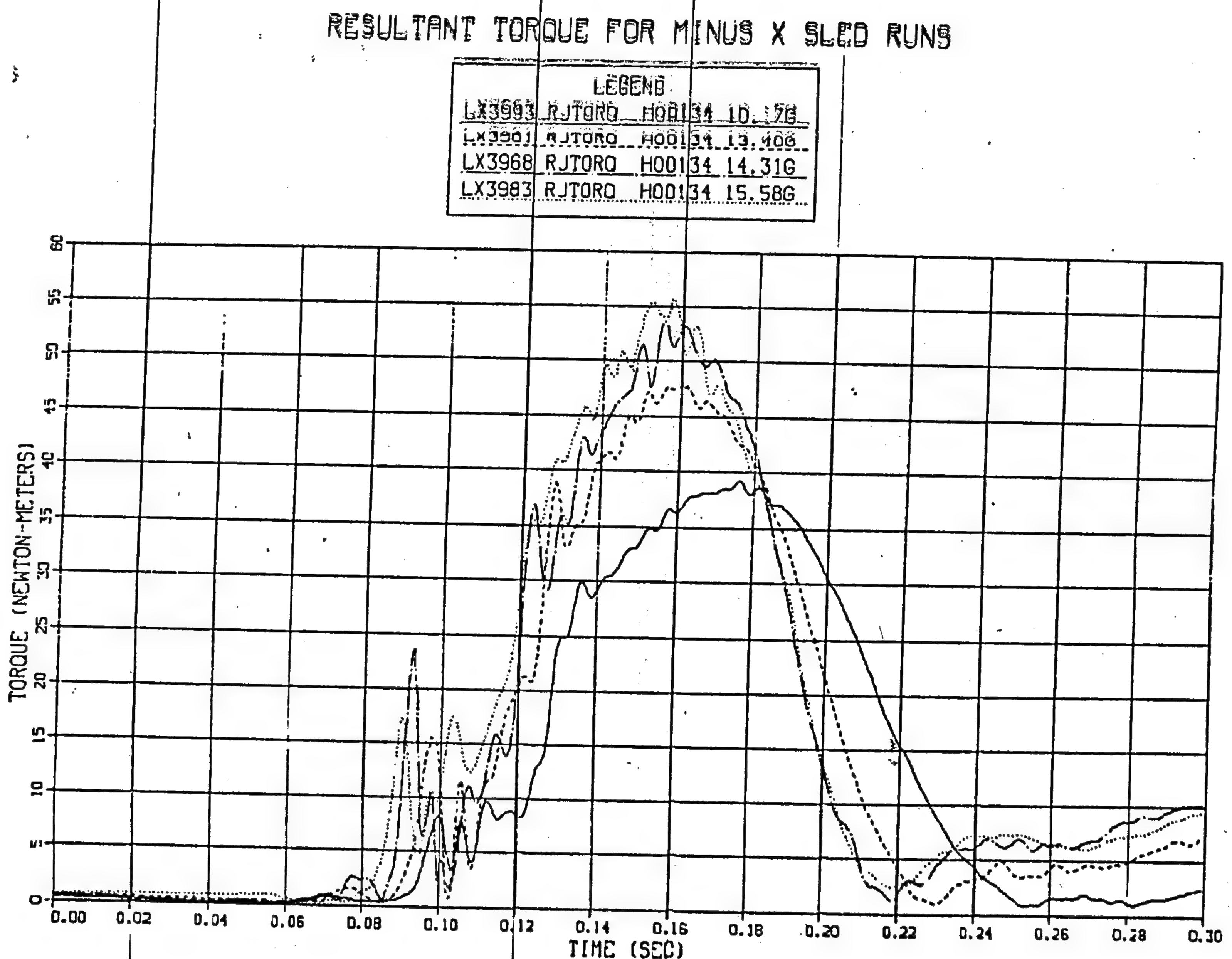

RESULTANT TORQUE FOR MINUS X SLED RUNS
LEGEND
LX3993 RJTORO H00134 10.?7G
LX3961 RJTORO H00134 13.40G
LX3968 RJTORO H00134 14.31G
LX3983 RJTORO H00134 15.58G
TORQUE (NEWTON-METERS)
0
5
10
15
20
25
30
35
40
45
50
55
60
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
0.28
0.30
TIME (SEC)

Fig 4g

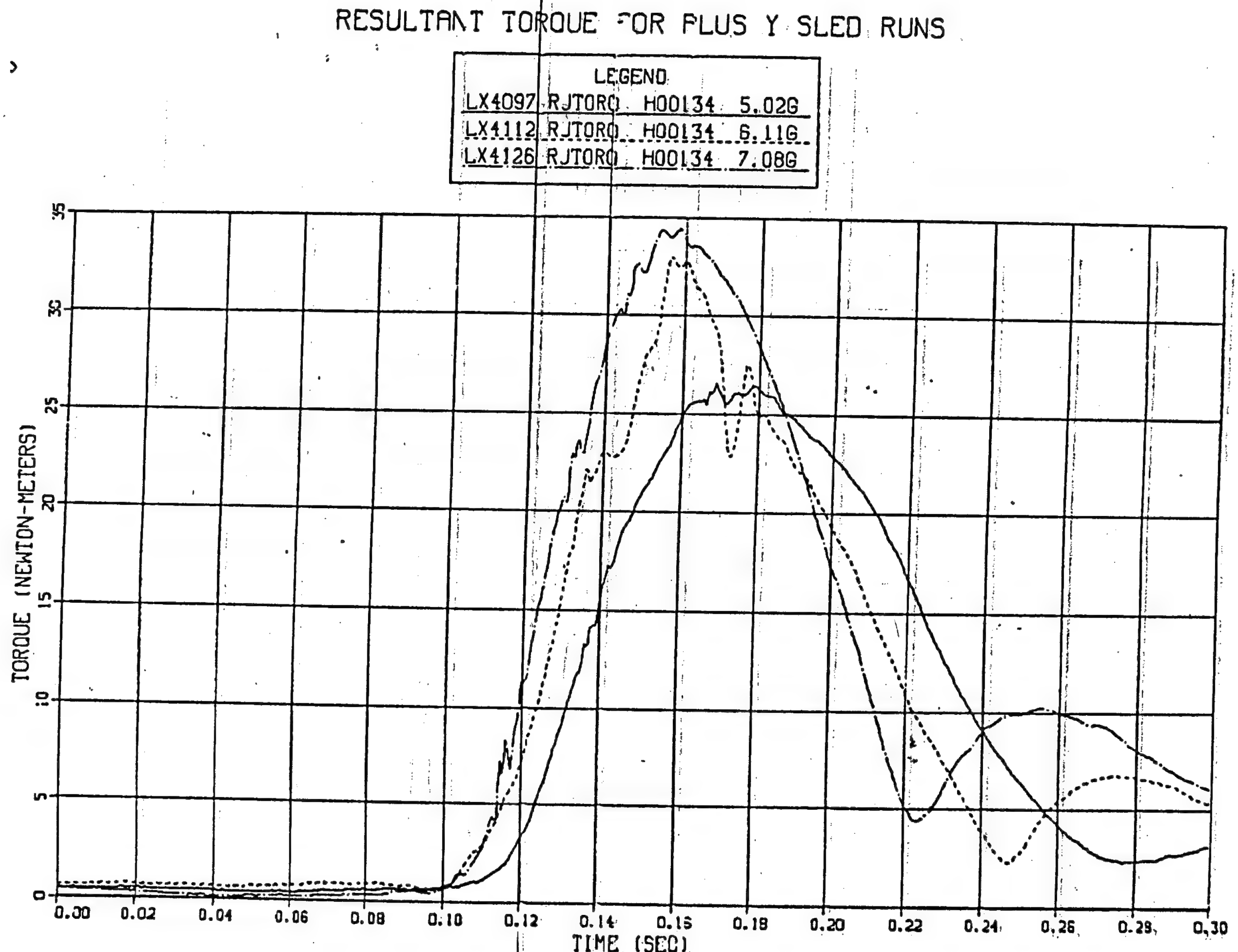

RESULTANT TORQUE FOR PLUS Y SLED RUNS
LEGEND
LX4097 RJTORQ H00134 5.02G
LX4112 RJTORQ H00134 6.11G
LX4126 RJTORQ H00134 7.08G
TORQUE (NEWTON-METERS)
0
5
10
15
20
25
30
35
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
0.28
0.30
TIME (SEC)

Fig 4b

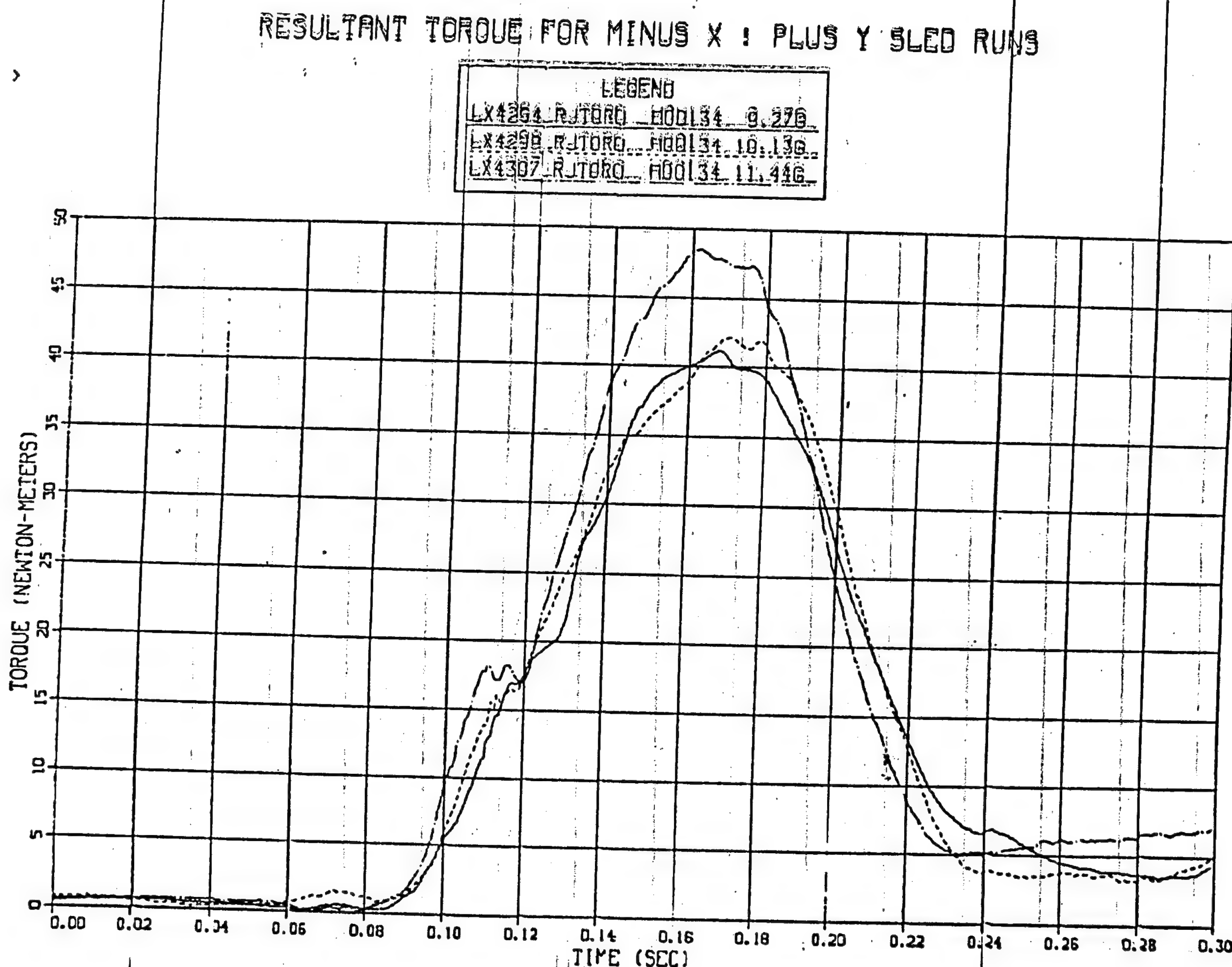

RESULTANT TORQUE FOR MINUS X : PLUS Y SLED RUNS
LEGEND
LX4264 RJTORQ H00134 9.27G
LX4298 RJTORQ H00134 10.13G
LX4307 RJTORQ H00134 11.44G
TORQUE (NEWTON-METERS)
0
5
10
15
20
25
30
35
40
45
50
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
0.28
0.30
TIME (SEC)

Fig 4C

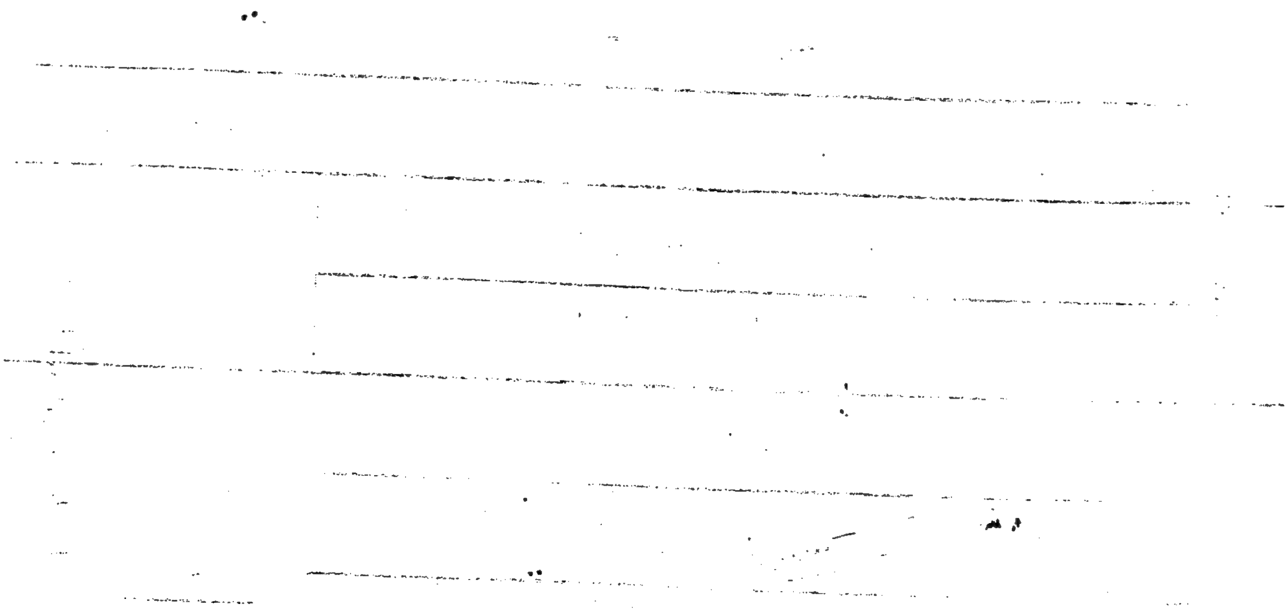
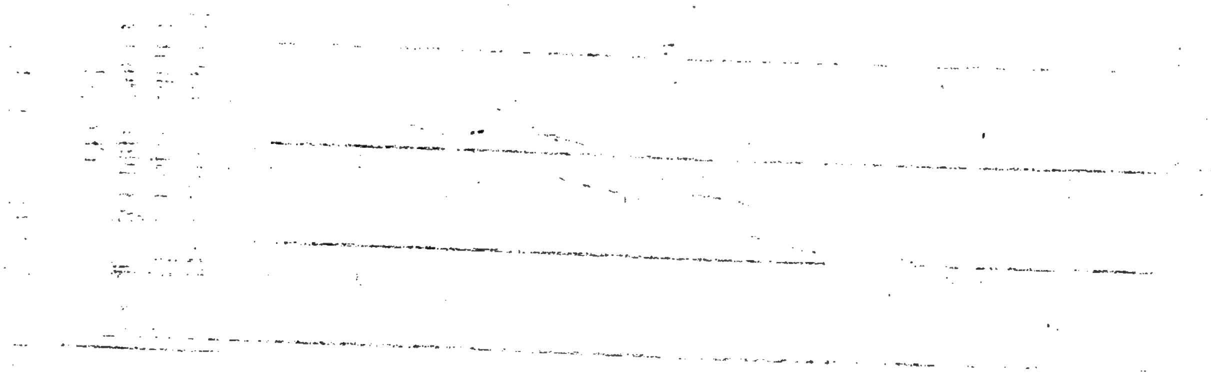


Figure 5. Head Injury Criteria (HIC) Time-Courses Across -X, +Y and -X+Y Vector Directions and Selected Accelerations For H134.



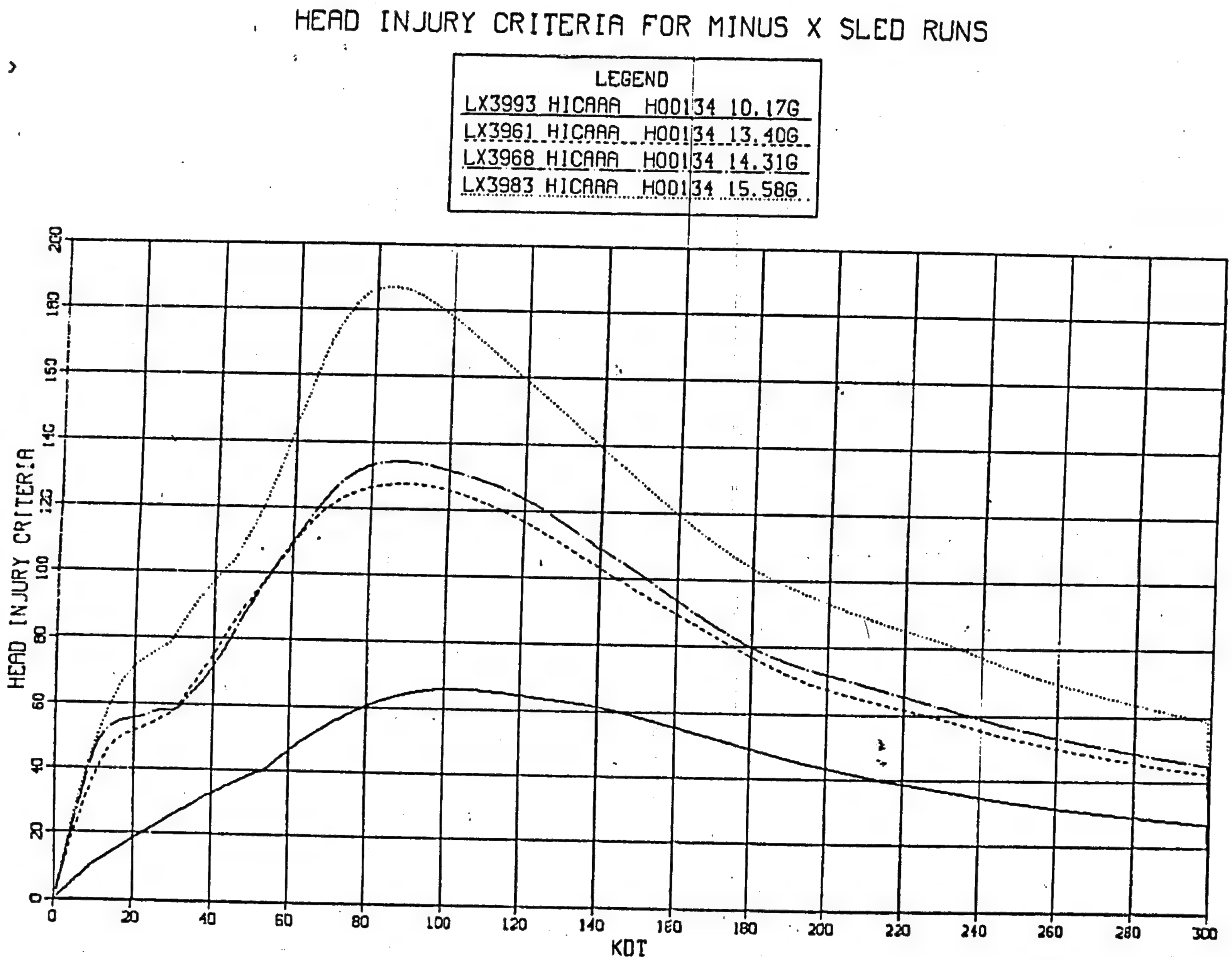

HEAD INJURY CRITERIA FOR MINUS X SLED RUNS
LEGEND
LX3993 HICAAA H00134 10.17G
LX3961 HICAAA H00134 13.40G
LX3968 HICAAA H00134 14.31G
LX3983 HICAAA H00134 15.58G
HEAD INJURY CRITERIA
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
KDT

Fig 5a

HEAD INJURY CRITERIA FOR PLUS Y SLED RUNS

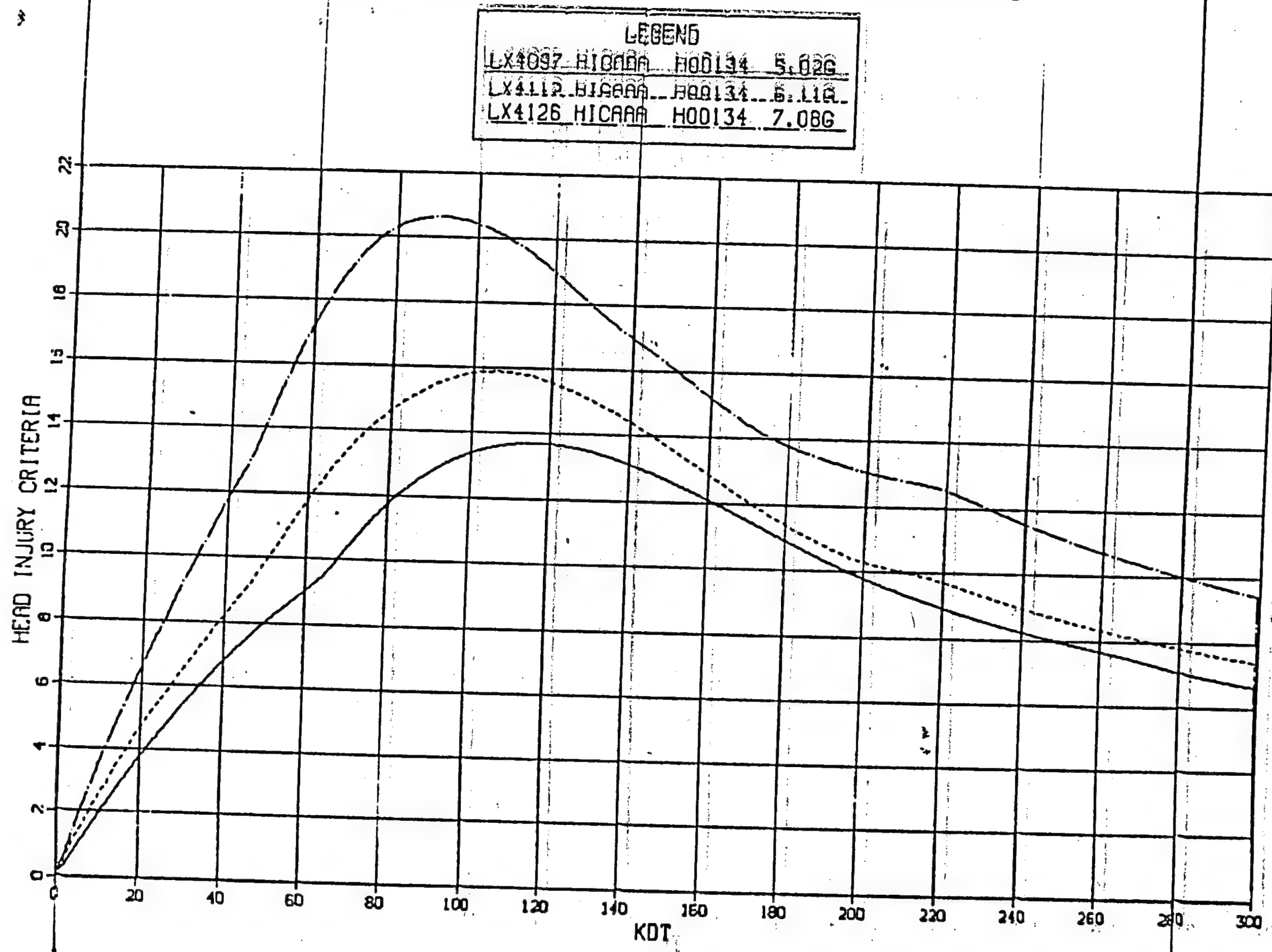


Fig 5b

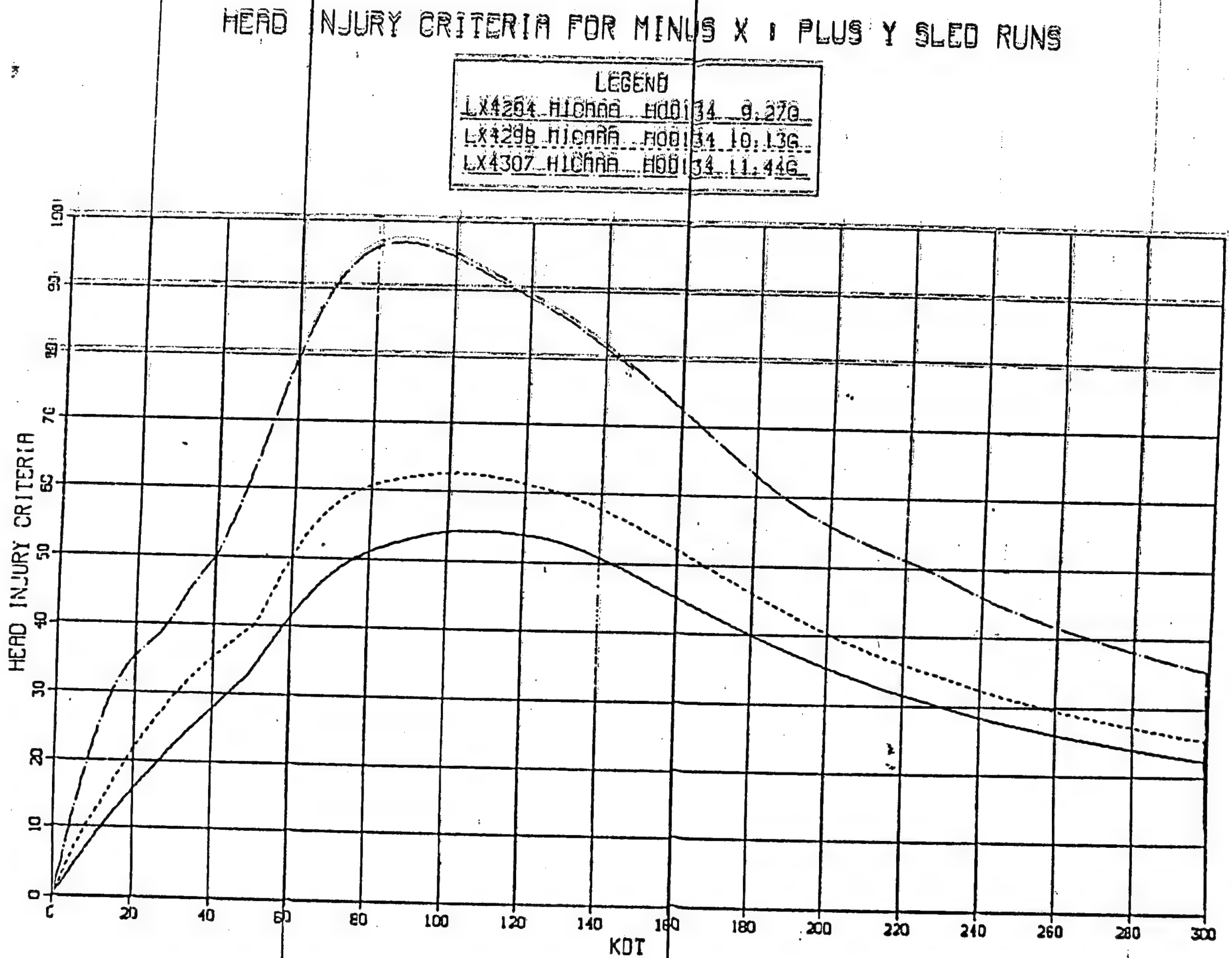

HEAD INJURY CRITERIA FOR MINUS X + PLUS Y SLED RUNS
LEGEND
LX4284 HICMAA H00134 9.27G
LX4298 HICMAA H00134 10.13G
LX4307 HICMAA H00134 11.44G
HEAD INJURY CRITERIA
KDT
0
10
20
30
40
50
60
70
80
90
100
120
140
160
180
200
220
240
260
280
300

Fig 5C

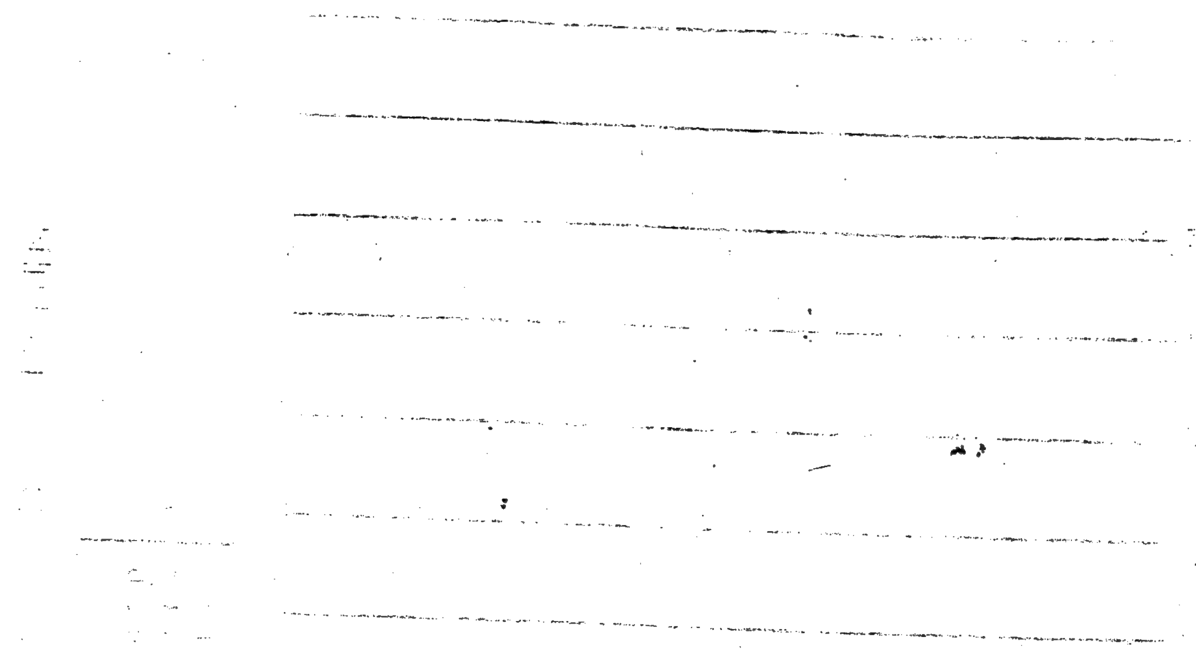
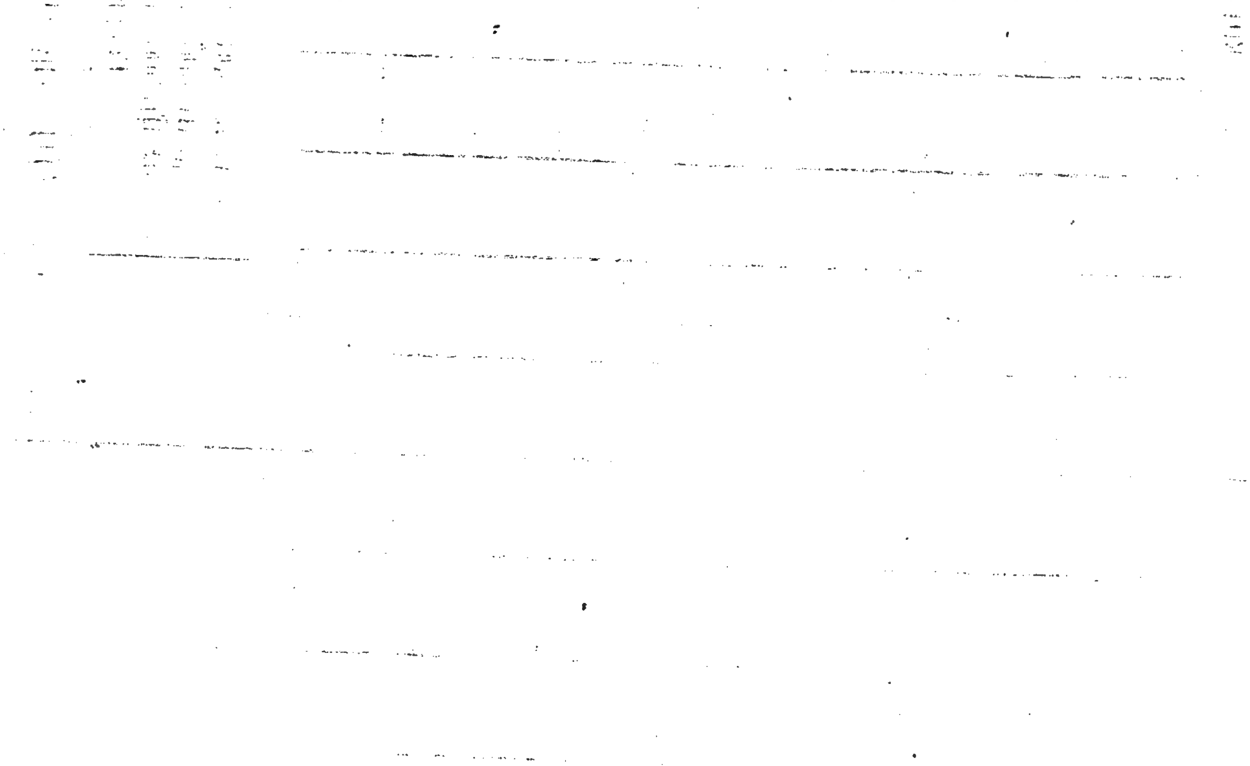


Figure 6. Shear Force Time-Course Comparisons for Subjects with Large (H132) and Small (H135) Heads Across Selected -X, +Y, and -X+Y Impacts



SHEAR FORCE FOR MINUS X SLED DIRECTION

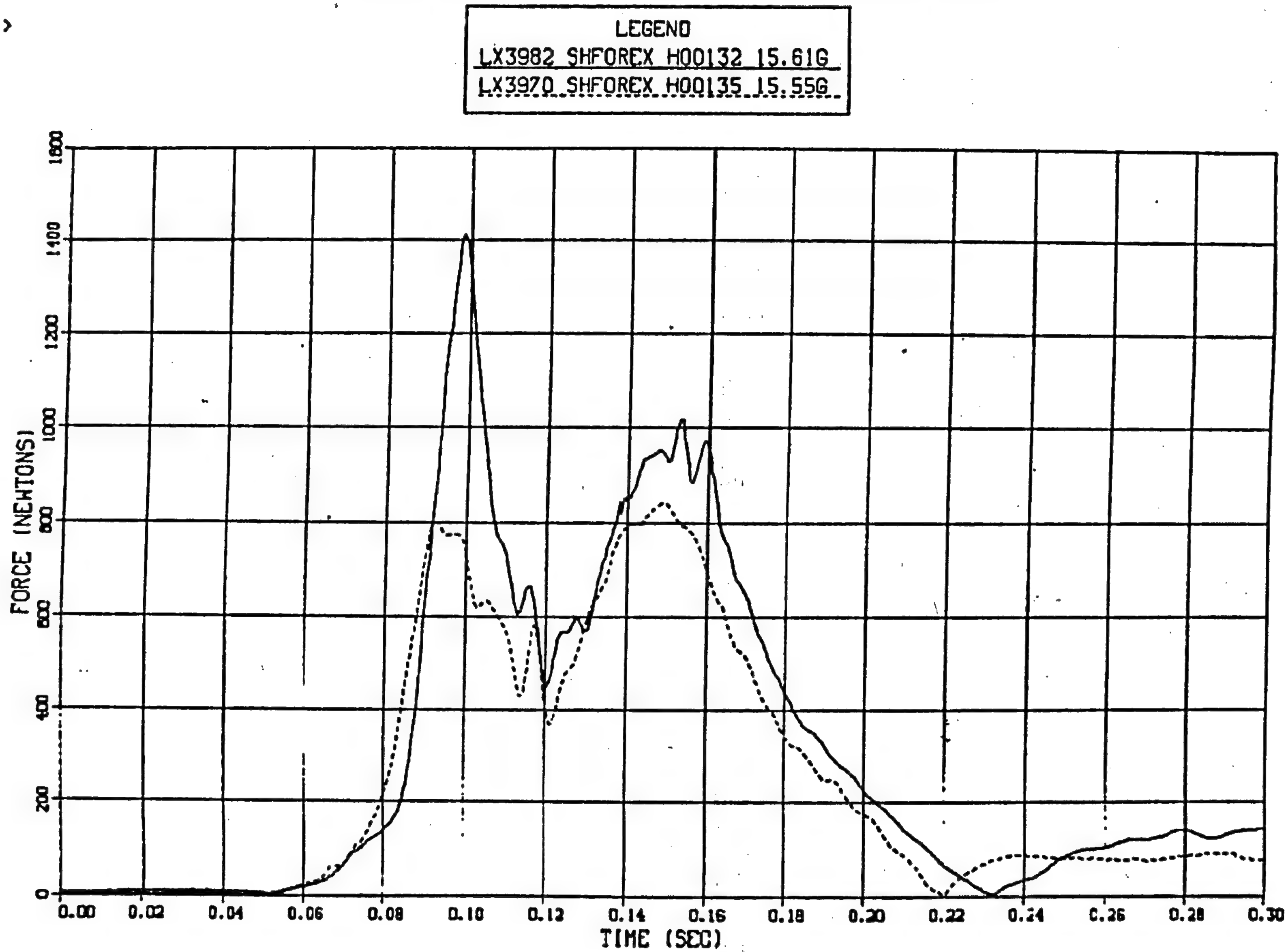


Fig 6a

SHEAR FORCE FOR MINUS X : PLUS Y SLED RUNS

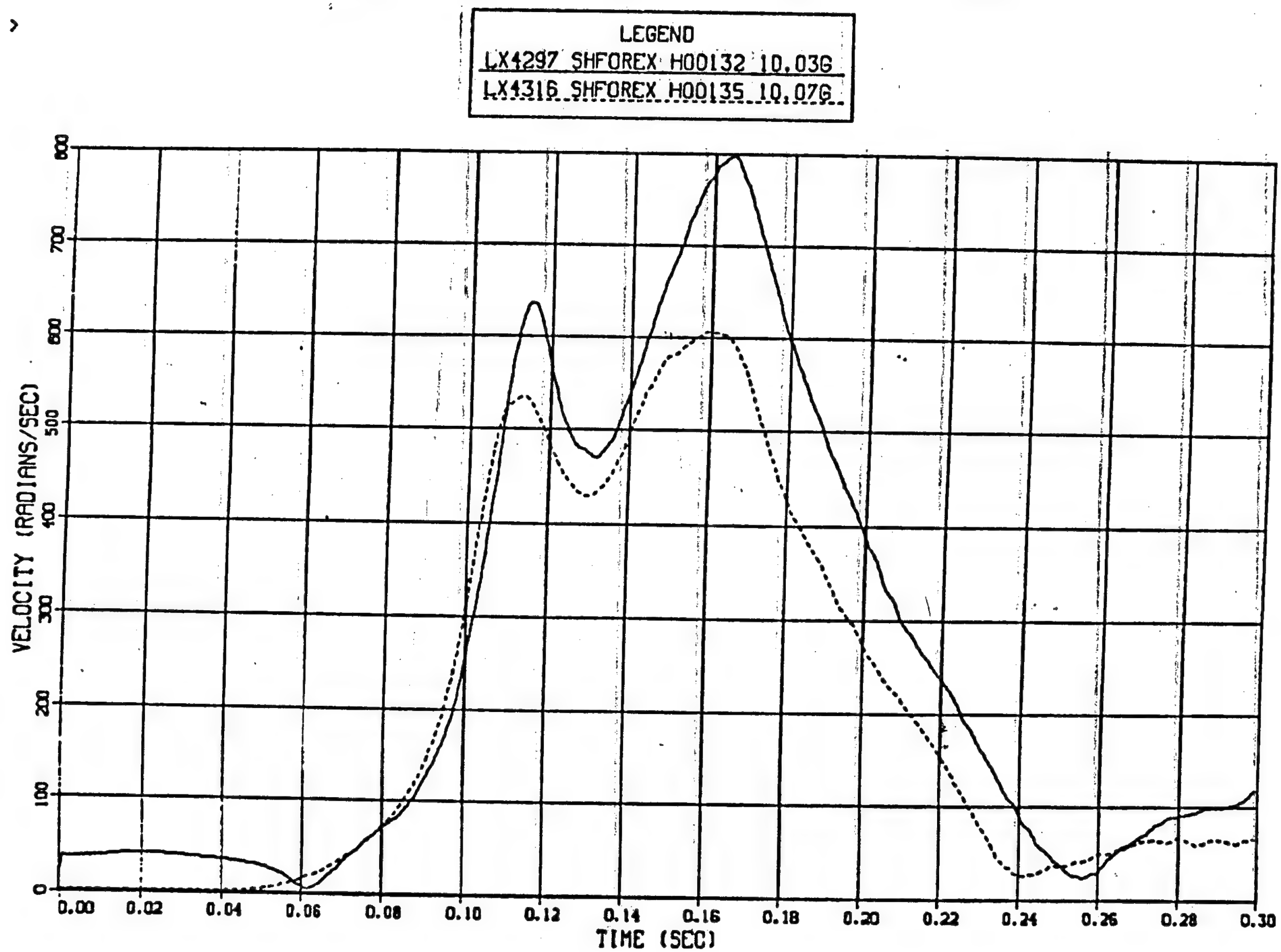
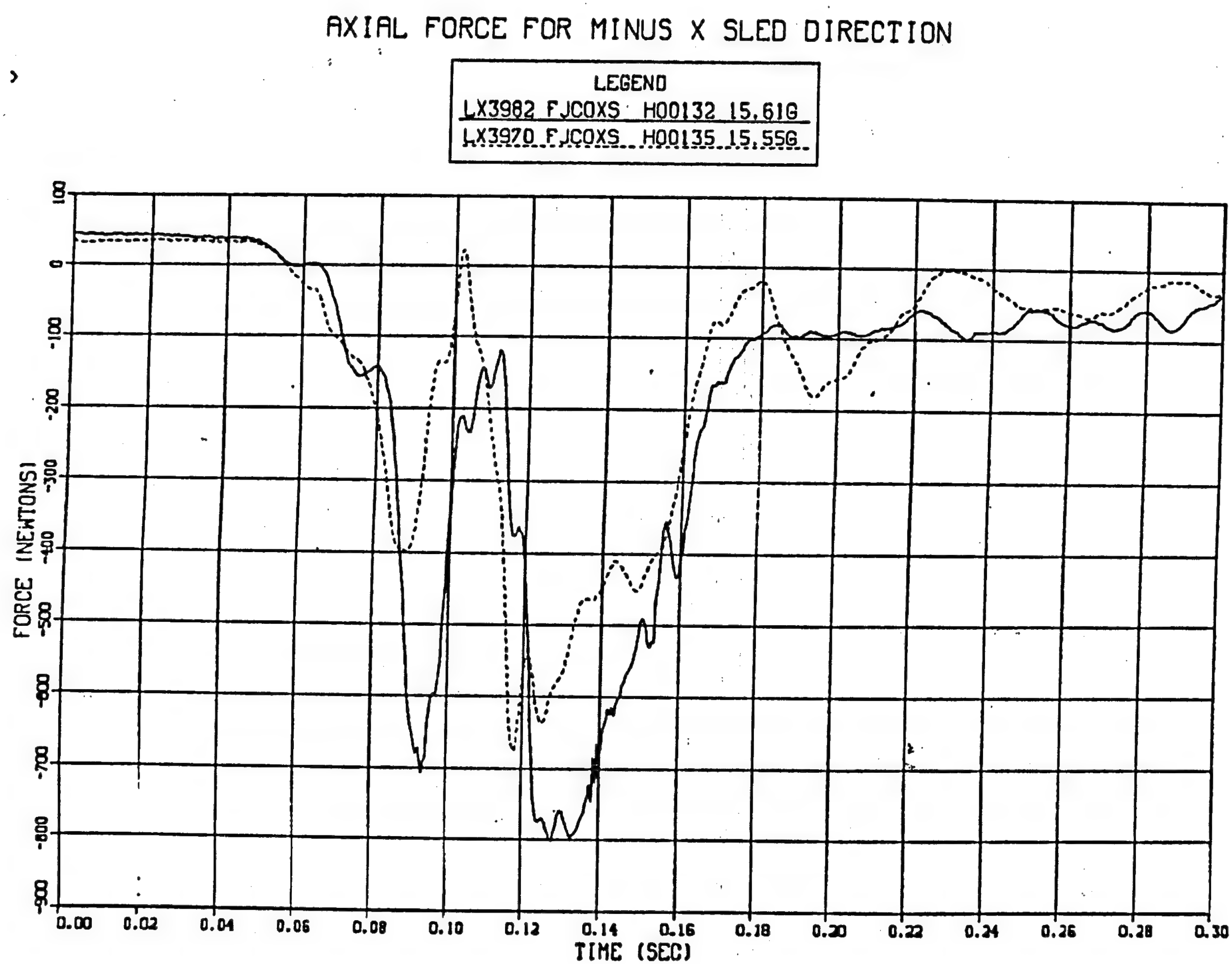


Fig 6 (

Figure 7. Axial Force Time-Course Comparisons for Subjects with Large (H132) and Small (H135) Heads Across Selected -X, +Y and -X+Y Impacts



AXIAL FORCE FOR MINUS X SLED DIRECTION
LEGEND
LX3982 FJCOXS H00132 15.61G
LX3970 FJCOXS H00135 15.55G
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
FORCE (NEWTONS)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
0.28
0.30
TIME (SEC)

Fig 7a

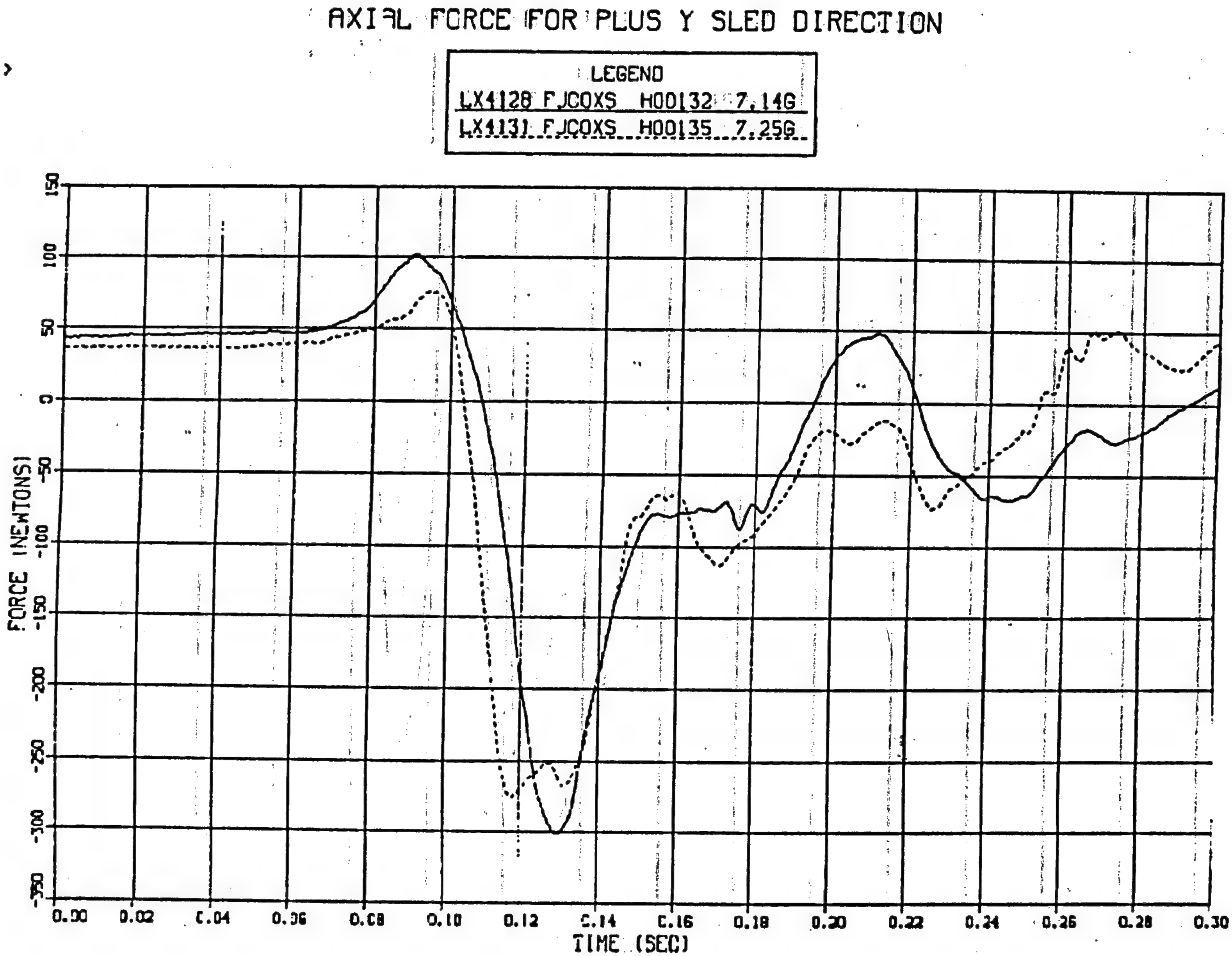

AXIAL FORCE FOR PLUS Y SLED DIRECTION
LEGEND
LX4128 FJCOXS H00132 7.14G
LX4131 FJCOXS H00135 7.25G
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
FORCE (NEWTONS)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
0.28
0.30
TIME (SEC)

Fig 7b

AXIAL FORCE FOR MINUS X : PLUS Y SLED RUNS

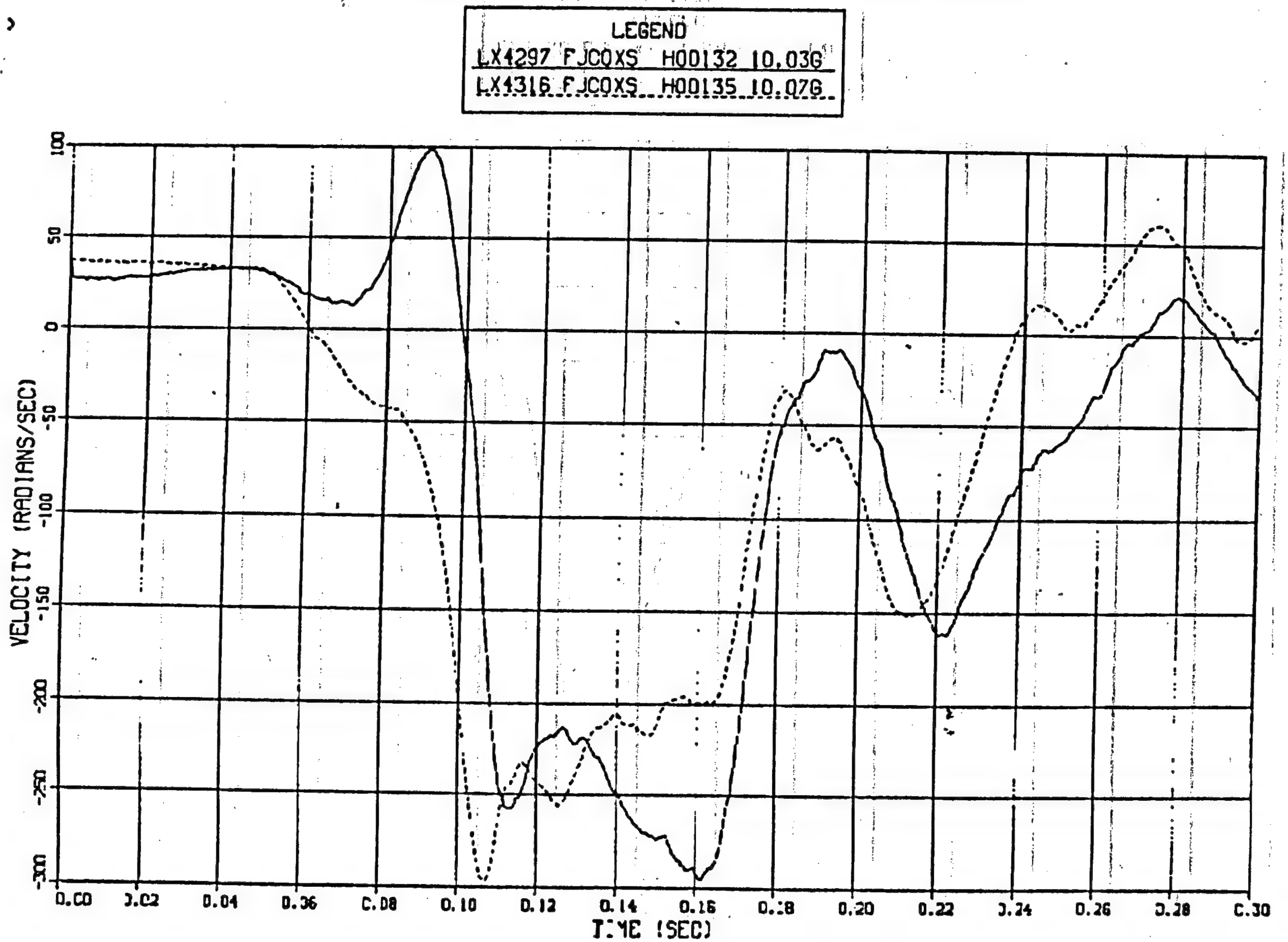
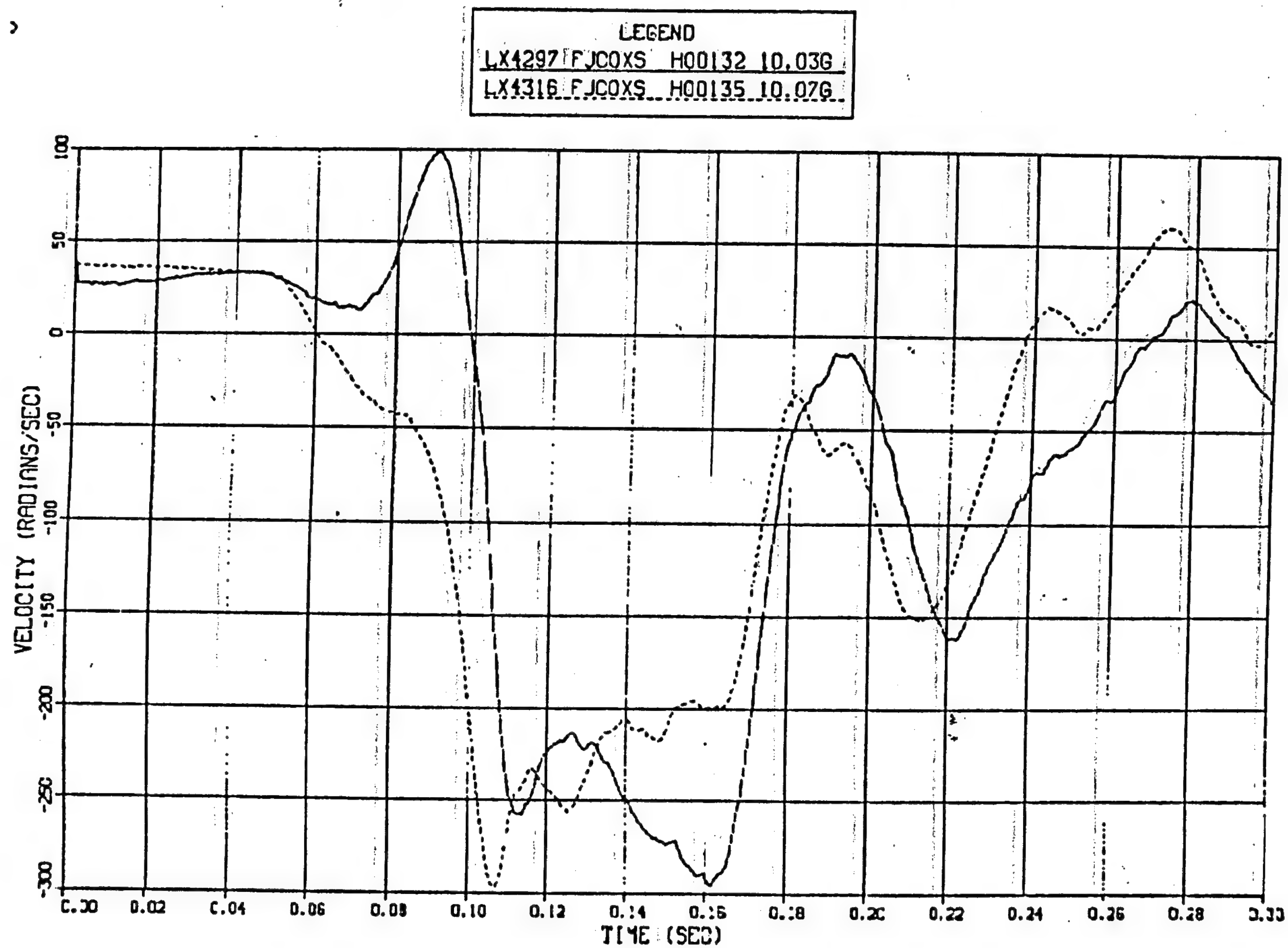


Fig 7c

AXIAL FORCE FOR MINUS X : PLUS Y SLED RUNS



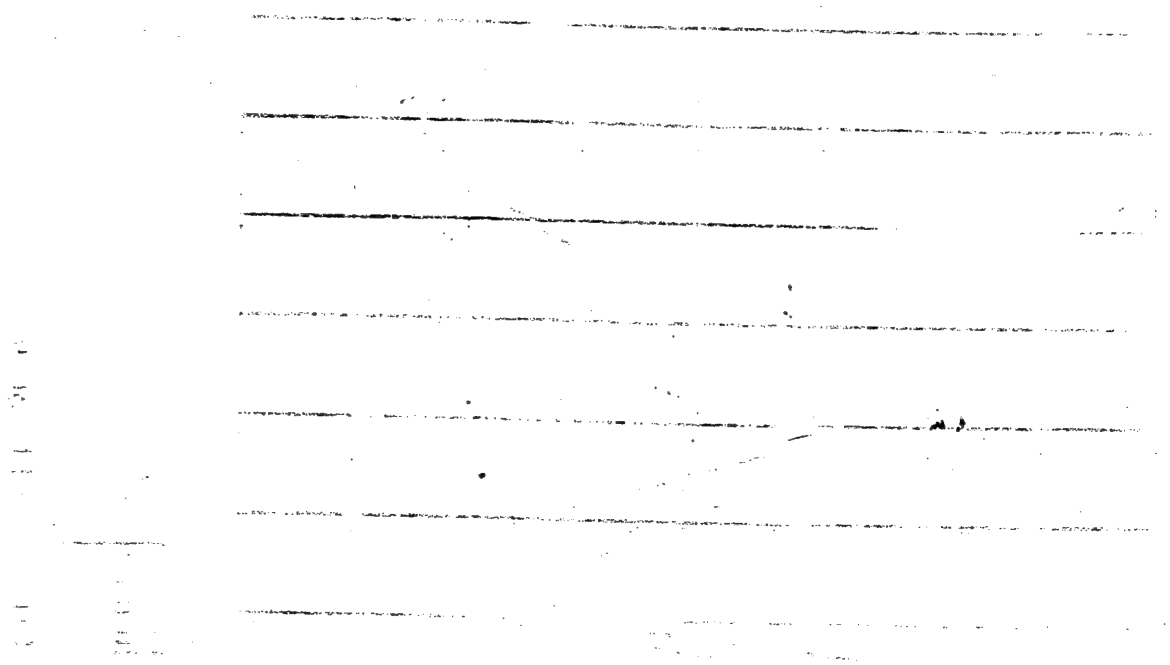


Figure 8. Resultant Torque Time-Course Comparisons for Subjects with Large (H132) and Small (H135) Heads Across -X, +Y and -X+Y Impacts

RESULTANT TORQUE FOR MINUS X SLED RUNS

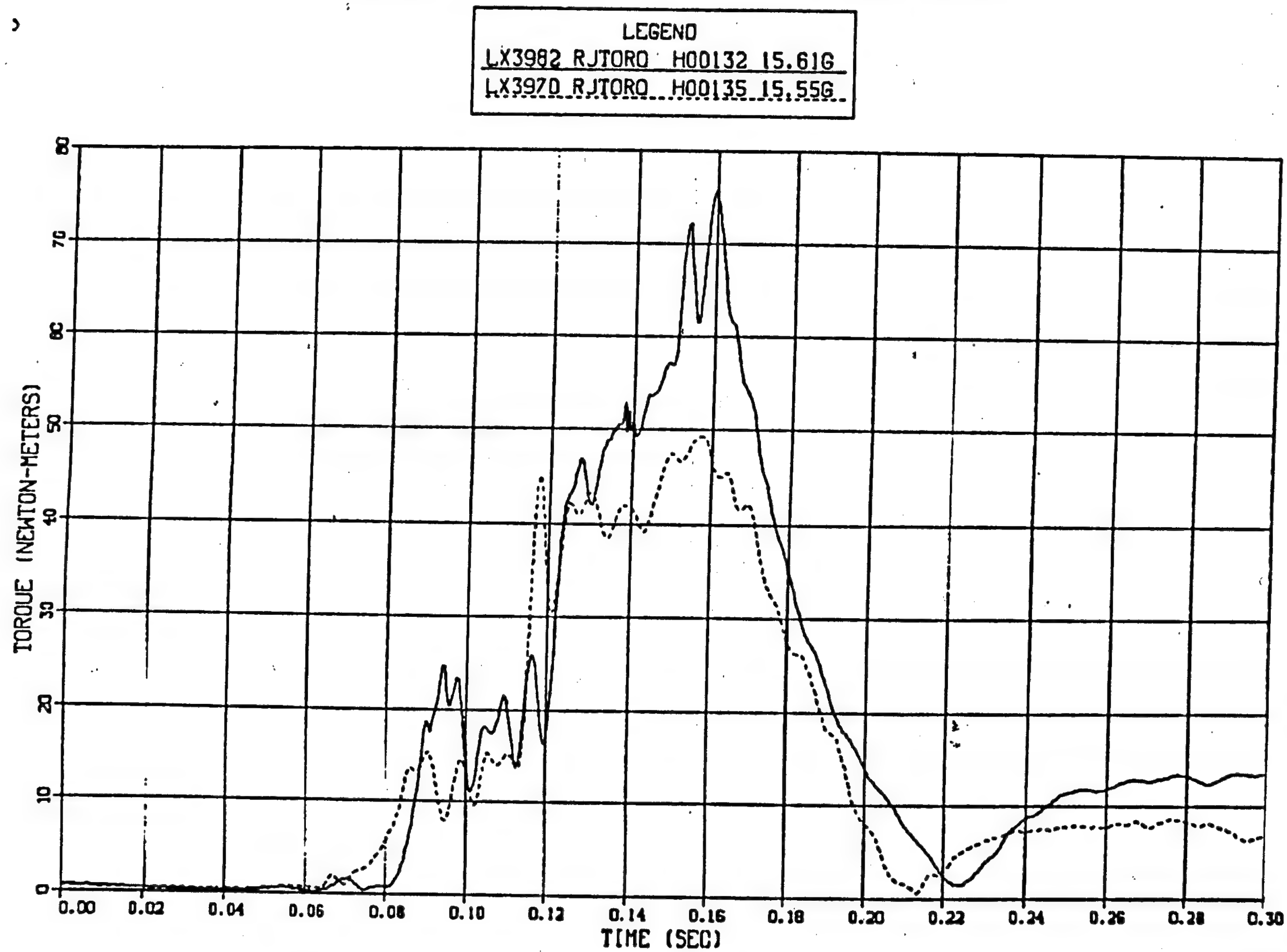


Fig 8 4

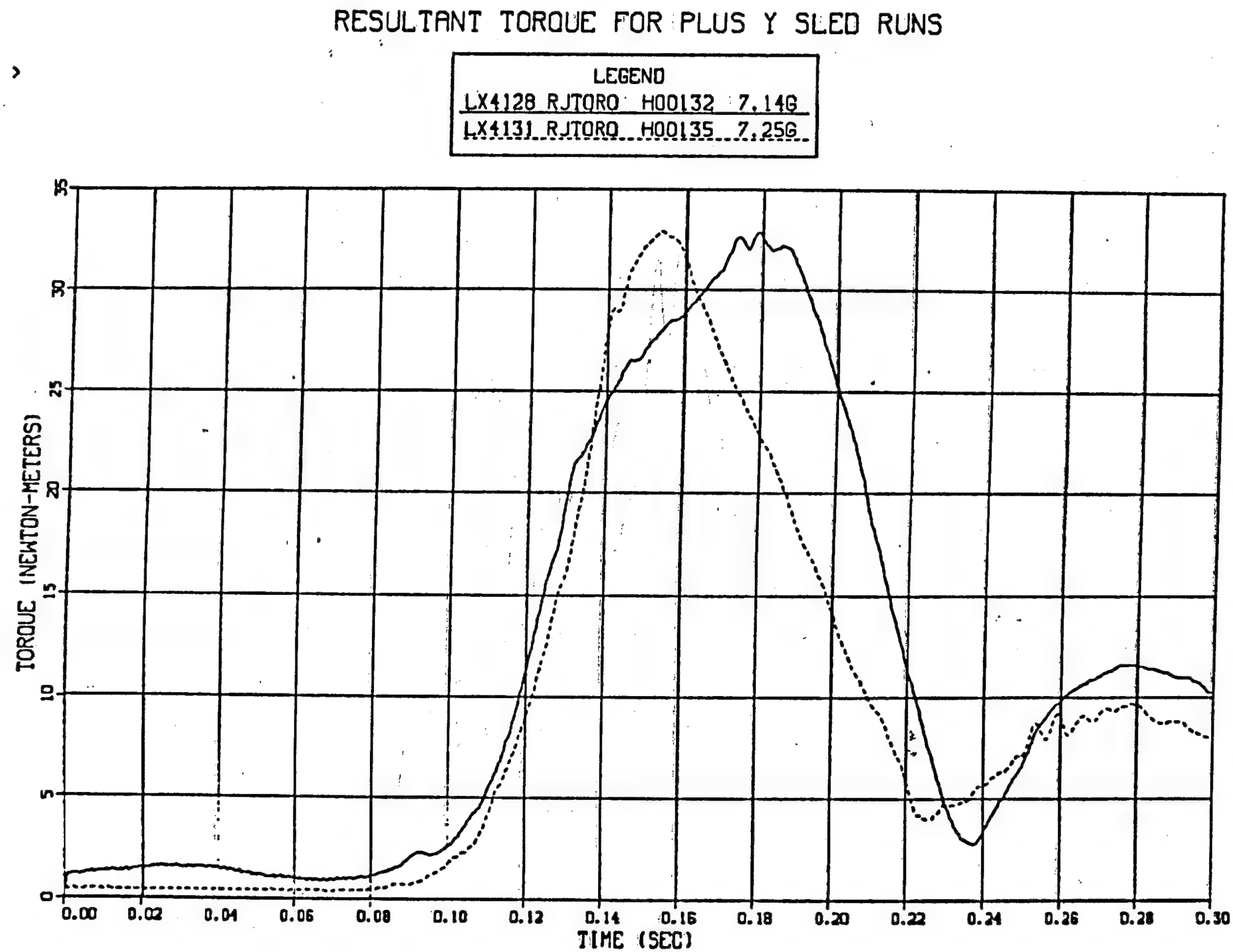
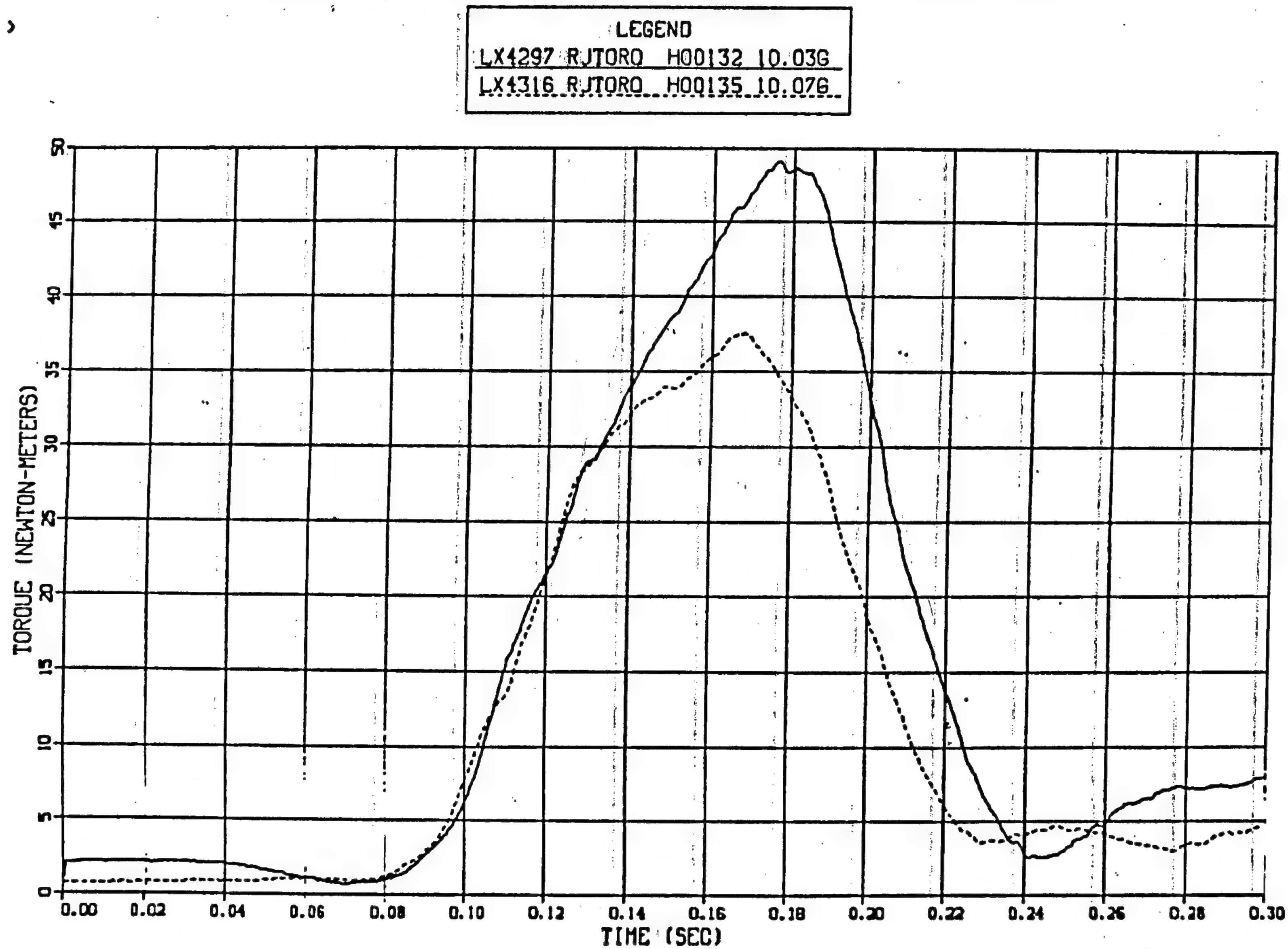

RESULTANT TORQUE FOR PLUS Y SLED RUNS
LEGEND
LX4128 RJTORO H00132 7.14G
LX4131 RJTORO H00135 7.25G
TORQUE (NEWTON-METERS)
0
5
10
15
20
25
30
35
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
0.28
0.30
TIME (SEC)

Fig 8b

RESULTANT TORQUE FOR MINUS X : PLUS Y SLED RUNS



APPENDIX

SUBJECT (H131-H136) INJURY-RELATED VARIABLE SUMMARY TABLES FOR SELECTED -X, +Y, AND -X+Y IMPACT ACCELERATIONS AT NBDL

SUBJECT H00131

*** Head Anatomical Configuration ***

Head Mass : 4.449 Kg.
Head Center of Gravity: X = +0.0084 Y = -0.0006 Z = +0.0317 Meters
Head / Neck Center of Gravity: X = +0.0190 Y = +0.0000 Z = +0.5800 Meters
Eignvalues: 1 = +0.02198 2 = +0.02350 3 = +0.01529

Principal Axis Matrix			Moment of inertia matrix in A.C.S.		
+0.82900	+0.00000	+0.55920	+0.019887	+0.000000	+0.003101
+0.00000	+1.00000	+0.00000	+0.000000	+0.023510	+0.000000
-0.55920	+0.00000	+0.82900	+0.003101	+0.000000	+0.017381

*** Minus X Sled Runs ***

	10 G-Level Run LX3908		13 G-Level Run LX3948		14 G-Level Run LX3987		15 G-Level Run LX3990	
	Max	Min	Max	Min	Max	Min	Max	Min
Force X-Axis	140.59	-711.44	120.85	-828.81	139.87	-1058.48	127.16	-982.90
Force Y-Axis	74.12	-76.47	26.99	77.77	56.72	-93.02	38.80	-131.41
Force Z-Axis	114.50	-404.53	44.34	-621.00	44.38	-721.15	45.03	-709.69
Force Result	788.51	4.63	980.34	15.66	1225.57	11.25	1180.26	14.98

	10 G-Level Run LX3993		13 G-Level Run LX3961		14 G-Level Run LX39~~68~~87		15 G-Level Run LX39~~83~~90	
	Max	Min	Max	Min	Max	Min	Max	Min
Torque X-Axis	8.66	-6.95	6.70	-2.49	7.56	-4.38	10.90	-3.77
Torque Y-Axis	27.48	-45.81	11.48	-51.92	13.69	-58.89	13.10	-55.22
Torque Z-Axis	1.44	-2.96	0.89	-1.58	3.28	-3.55	2.56	-2.71
Torque Result	45.81	0.41	51.93	0.09	58.90	0.10	56.30	0.17

	10 G-Level Run LX3993		13 G-Level Run LX3961		14 G-Level Run LX39~~68~~87		15 G-Level Run LX39~~83~~90	
	HIC nbr	Width	HIC nbr	Width	HIC nbr	Width	HIC nbr	Width
HIC X-Axis	47.77	80.00	84.55	76.50	114.03	75.00	112.08	74.50
HIC Y-Axis	0.03	150.50	0.04	160.00	0.16	93.00	0.24	91.00
HIC Z-Axis	9.33	61.50	14.81	53.50	19.79	47.50	21.08	44.00
Resultant HIC	65.33	114.00	112.04	94.50	153.53	83.50	155.58	83.00

SUBJECT H00131

*** Plus Y Sled Runs ***

DID

	5 G-Level Run LX4089 Max	Min	6 G-Level Run LX4109 Max	Min	6 G-Level Run LX4138 Max	Min	7 G-Level Run LX4124 Max	Min
Force X-Axis	43.83	-213.44	63.95	-218.45	58.28	-192.78	50.69	-190.52
Force Y-Axis	412.69	-46.53	400.74	-69.48	403.64	-78.89	403.69	-88.93
Force Z-Axis	54.85	-198.98	53.97	-309.86	75.07	-241.51	69.86	-323.39
Force Result	440.67	39.02	473.42	41.12	443.29	43.57	494.31	39.76

	5 G-Level Run LX4089 Max	Min	6 G-Level Run LX4109 Max	Min	6 G-Level Run LX4138 Max	Min	7 G-Level Run LX4124 Max	Min
Torque X-Axis	2.67	-32.58	4.32	-32.48	6.33	-35.00	7.09	-33.13
Torque Y-Axis	7.09	-11.98	7.10	-11.02	6.33	-11.24	8.92	-11.28
Torque Z-Axis	9.57	-1.86	11.70	-2.91	12.67	-3.13	12.95	-4.86
Torque Result	35.79	0.56	35.33	0.07	36.78	.71	35.41	0.25

	5 G-Level Run LX4089 HIC nbr	Width	6 G-Level Run LX4109 HIC nbr	Width	6 G-Level Run LX4138 HIC nbr	Width	7 G-Level Run LX4124 HIC nbr	Width
HIC X-Axis	11.95	94.00	12.65	94.00	10.85	97.50	13.02	84.50
HIC Y-Axis	0.24	129.00	0.20	130.00	0.52	73.00	0.41	68.00
HIC Z-Axis	1.19	59.50	2.59	64.00	3.18	67.00	2.66	60.00
Resultant HIC	15.28	95.00	17.85	101.50	16.92	107.50	18.09	94.00

*** Minus X / Plus Y ***

	7 G-Level Run LX4242 Max	Min	10 G-Level Run LX4251 Max	Min
Force X-Axis	6.81	-395.81	98.05	-700.19
Force Y-Axis	274.63	-2.14	394.24	-81.61
Force Z-Axis	51.17	-155.54	42.81	-467.41
Force Result	479.87	22.17	877.93	21.56

	7 G-Level Run LX4242 Max	Min	10 G-Level Run LX4251 Max	Min
Torque X-Axis	0.20	-20.71	6.91	-28.93
Torque Y-Axis	0.76	-27.23	7.37	-44.60
Torque Z-Axis	7.71	-2.34	12.52	-5.17
Torque Result	31.48	0.17	51.52	0.35

	7 G-Level Run LX4242 HIC nbr	Width	10 G-Level Run LX4251 HIC nbr	Width
HIC X-Axis	15.87	104.00	55.08	69.50
HIC Y-Axis	0.13	77.00	2.15	54.00
HIC Z-Axis	3.50	67.50	13.18	57.50
Resultant HIC	22.42	113.00	83.28	106.50

NBR

SUBJECT H00132

*** Head Anatomical Configuration ***

Head Mass : 4.523 Kg.
Head Center of Gravity: X = +0.0084 Y = -0.0006 Z = +0.0318 Meters
Head / Neck Center of Gravity: X = +0.0190 Y = +0.0000 Z = +0.5800 Meters
Eignvalues: 1 = +0.02259 2 = +0.02415 3 = +0.01572

Principal Axis Matrix			Moment of inertia matrix in A.C.S.		
+0.82900	+0.00000	+0.55920	+0.020440	+0.000000	+0.003185
+0.00000	+1.00000	+0.00000	+0.000000	+0.024150	+0.000000
-0.55920	+0.00000	+0.82900	+0.003185	+0.000000	+0.017867

*** Minus X Sled Runs ***

	10 G-Level		13 G-Level		14 G-Level		15 G-Level	
	Run LX3989		Run LX3950		Run LX3957		Run LX3982	
	Max	Min	Max	Min	Max	Min	Max	Min
Force X-Axis	55.43	-691.57	118.72	-1535.00	110.60	-1199.90	143.99	-1395.33
Force Y-Axis	11.89	-88.28	64.71	-194.54	45.75	-177.12	23.92	-214.45
Force Z-Axis	80.33	-317.61	42.95	-983.66	44.89	-629.76	44.56	-801.69
Force Result	750.09	22.59	1823.22	4.61	1252.74	16.66	1514.52	8.89

	10 G-Level		13 G-Level		14 G-Level		15 G-Level	
	Run LX3989		Run LX3950		Run LX3957		Run LX3982	
	Max	Min	Max	Min	Max	Min	Max	Min
Torque X-Axis	6.39	-0.86	11.19	-15.49	7.80	-3.22	11.73	-6.22
Torque Y-Axis	4.54	-39.89	18.17	-68.34	11.66	-56.12	13.58	-75.11
Torque Z-Axis	0.62	-3.00	7.42	-4.79	2.59	-5.25	1.23	-4.15
Torque Result	40.37	0.10	68.58	0.11	56.59	0.34	75.71	0.11

	10 G-Level		13 G-Level		14 G-Level		15 G-Level	
	HIC nbr	Width	HIC nbr	Width	HIC nbr	Width	HIC nbr	Width
	Run LX3989		Run LX3950		Run LX3957		Run LX3982	
HIC X-Axis	40.62	81.50	93.49	72.50	118.32	74.50	112.06	65.00
HIC Y-Axis	0.02	184.00	0.24	187.00	0.11	212.00	0.08	66.50
HIC Z-Axis	6.25	75.50	16.61	19.50	13.42	41.00	29.03	41.00
Resultant HIC	50.01	94.50	126.49	83.50	146.99	81.00	167.47	83.00

SUBJECT H00132

*** Plus Y Sled Runs ***

	5 G-Level Run LX4090 Max	5 G-Level Run LX4090 Min	6 G-Level Run LX4110 Max	6 G-Level Run LX4110 Min	7 G-Level Run LX4128 Max	7 G-Level Run LX4128 Min
Force X-Axis	42.26	-178.27	35.75	-315.75	60.02	-287.66
Force Y-Axis	291.58	-19.82	414.47	-89.96	392.60	-138.20
Force Z-Axis	77.41	-168.80	73.51	-320.10	101.81	-301.20
Force Result	343.08	38.09	539.94	28.51	495.36	44.30

	5 G-Level Run LX4090 Max	5 G-Level Run LX4090 Min	6 G-Level Run LX4110 Max	6 G-Level Run LX4110 Min	7 G-Level Run LX4128 Max	7 G-Level Run LX4128 Min
Torque X-Axis	1.92	-19.70	7.49	-29.34	10.84	-21.67
Torque Y-Axis	3.46	-8.27	5.56	-13.79	5.33	-15.05
Torque Z-Axis	8.00	-1.32	11.35	-2.96	13.85	-3.81
Torque Result	22.49	0.23	33.73	0.27	32.89	0.26

	5 G-Level Run LX4090 HIC nbr	5 G-Level Run LX4090 Width	6 G-Level Run LX4110 HIC nbr	6 G-Level Run LX4110 Width	7 G-Level Run LX4128 HIC nbr	7 G-Level Run LX4128 Width
HIC X-Axis	5.94	124.00	14.78	101.00	12.53	94.00
HIC Y-Axis	0.09	214.50	0.23	26.50	0.13	216.00
HIC Z-Axis	1.74	80.00	2.01	54.00	3.69	61.00
Resultant HIC	9.01	137.50	19.71	104.00	18.77	104.50

*** Minus X / Plus Y ***

	7 G-Level Run LX4261 Max	7 G-Level Run LX4261 Min	10 G-Level Run LX4297 Max	10 G-Level Run LX4297 Min	11 G-Level Run LX4306 Max	11 G-Level Run LX4306 Min
Force X-Axis	26.95	-568.61	64.44	-752.94	31.41	-713.83
Force Y-Axis	299.74	-60.54	311.01	-104.52	341.89	-74.08
Force Z-Axis	44.64	-202.31	98.66	-295.38	45.72	-301.87
Force Result	650.44	14.79	848.15	17.48	834.00	26.42

	7 G-Level Max Run LX4261	7 G-Level Min Run LX4261	10 G-Level Max Run LX4297	10 G-Level Min Run LX4297	11 G-Level Max Run LX4306	11 G-Level Min Run LX4306
Torque X-Axis	4.35	-20.38	6.62	-18.26	4.00	-21.82
Torque Y-Axis	2.03	-35.51	5.30	-45.39	3.26	-46.70
Torque Z-Axis	8.88	-1.31	10.91	-4.28	10.06	-2.59
Torque Result	40.70	0.46	49.07	0.52	51.65	0.62

	7 G-Level Run LX4261 HIC nbr	7 G-Level Run LX4261 Width	10 G-Level Run LX4297 HIC nbr	10 G-Level Run LX4297 Width	11 G-Level Run LX4306 HIC nbr	11 G-Level Run LX4306 Width
HIC X-Axis	36.62	103.50	45.65	77.00	50.09	84.00
HIC Y-Axis	0.46	44.00	1.22	32.50	0.57	28.00
HIC Z-Axis	3.15	56.50	7.04	53.50	8.83	53.00
Resultant HIC	45.72	108.50	60.14	95.00	66.50	95.50

SUBJECT H00133

*** Head Anatomical Configuration ***

Head Mass : 4.170 Kg.
Head Center of Gravity: X = +0.0082 Y = -0.0005 Z = +0.0310 Meters
Head / Neck Center of Gravity: X = +0.0190 Y = +0.0000 Z = +0.5800 Meters
Eignvalues: 1 = +0.01973 2 = +0.02110 3 = +0.01373

Principal Axis Matrix

+0.82900	+0.00000	+0.55920
+0.00000	+1.00000	+0.00000
-0.55920	+0.00000	+0.82900

Moment of inertia matrix in A.C.S.

+0.017853	+0.000000	+0.002781
+0.000000	+0.021100	+0.000000
+0.002781	+0.000000	+0.015605

*** Minus X Sled Runs ***

	10 G-Level Run LX3998		13 G-Level Run LX3951		14 G-Level Run LX3963		15 G-Level Run LX3986	
	Max	Min	Max	Min	Max	Min	Max	Min
Force X-Axis	96.70	-757.19	96.06	-855.84	115.21	-867.71	53.09	-552.93
Force Y-Axis	34.28	-78.60	70.55	-142.20	85.05	-149.16	26.64	-99.08
Force Z-Axis	40.77	-740.92	40.78	-726.01	40.65	-867.30	83.78	-414.60
Force Result	978.92	4.99	1122.77	11.35	1147.43	10.67	671.05	2.96

	10 G-Level Run LX3998		13 G-Level Run LX3951		14 G-Level Run LX3963		15 G-Level Run LX3986	
	Max	Min	Max	Min	Max	Min	Max	Min
Torque X-Axis	9.22	-2.39	6.14	-4.61	13.39	-8.25	9.22	-2.39
Torque Y-Axis	3.14	-38.31	9.29	-48.99	11.65	-55.96	3.14	-38.31
Torque Z-Axis	1.34	-1.47	4.11	-3.40	3.96	-3.10	1.34	-1.47
Torque Result	39.15	0.15	49.06	0.03	56.19	0.13	39.15	0.15

	10 G-Level Run LX3998		13 G-Level Run LX3951		14 G-Level Run LX3963		15 G-Level Run LX3986	
	HIC nbr	Width	HIC nbr	Width	HIC nbr	Width	HIC nbr	Width
HIC X-Axis	43.28	97.00	86.99	76.50	96.61	77.50	131.30	77.00
HIC Y-Axis	0.06	73.00	0.06	216.00	0.09	144.00	0.20	77.50
HIC Z-Axis	5.11	62.50	17.29	48.00	15.57	50.50	23.83	41.50
Resultant HIC	55.32	106.50	120.17	94.00	125.77	89.00	177.62	88.50

SUBJECT H00133

*** Plus Y Sled Runs ***

	5 G-Level Run LX4093		6 G-Level Run LX4111		7 G-Level Run LX4125	
	Max	Min	Max	Min	Max	Min
Force X-Axis	43.51	-163.40	27.00	-188.44	24.50	-274.48
Force Y-Axis	364.71	-34.23	395.26	-51.60	577.36	-108.84
Force Z-Axis	47.67	-159.00	71.89	-276.20	68.77	-369.02
Force Result	380.65	40.25	444.90	30.88	647.16	36.46

	5 G-Level Run LX4093		6 G-Level Run LX4111		7 G-Level Run LX4125	
	Max	Min	Max	Min	Max	Min
Torque X-Axis	2.84	-28.16	3.91	-33.20	8.71	-44.60
Torque Y-Axis	4.70	-10.12	3.30	-9.25	4.26	-12.65
Torque Z-Axis	9.38	-0.27	10.32	-1.15	16.68	-2.43
Torque Result	30.38	0.49	35.42	0.69	49.05	0.64

	5 G-Level Run LX4093		6 G-Level Run LX4111		7 G-Level Run LX4125	
	HIC nbr	Width	HIC nbr	Width	HIC nbr	Width
HIC X-Axis	11.62	104.50	16.36	97.00	24.85	74.00
HIC Y-Axis	0.18	148.50	0.25	135.00	0.23	79.50
HIC Z-Axis	0.63	268.00	1.72	61.50	3.95	44.00
Resultant HIC	13.74	106.00	21.05	102.50	32.93	78.50

*** Minus X / Plus Y ***

	7 G-Level Run LX4236		10 G-Level Run LX4240	
	Max	Min	Max	Min
Force X-Axis	3.74	-343.93	11.38	-447.93
Force Y-Axis	338.00	-8.19	499.11	-39.79
Force Z-Axis	45.92	-159.02	52.51	-273.00
Force Result	497.62	213.34	643.11	12.44

	7 G-Level Run LX4236		10 G-Level Run LX4240	
	Max	Min	Max	Min
Torque X-Axis	1.84	-22.29	2.80	-26.65
Torque Y-Axis	0.34	-20.87	0.80	-25.14
Torque Z-Axis	9.18	-0.11	11.45	-0.94
Torque Result	31.33	0.09	36.51	0.22

	7 G-Level Run LX4236		10 G-Level Run LX4240	
	HIC nbr	Width	HIC nbr	Width
HIC X-Axis	26.26	107.50	39.86	104.50
HIC Y-Axis	0.18	45.50	0.33	44.50
HIC Z-Axis	1.04	115.00	3.98	57.50
Resultant HIC	29.97	108.50	50.50	106.50

SUBJECT H00134

*** Head Anatomical Configuration ***

Head Mass : 4.278 Kg.
Head Center of Gravity: X = +0.0083 Y = -0.0005 Z = +0.0313 Meters
Head / Neck Center of Gravity: X = +0.0190 Y = +0.0000 Z = +0.5800 Meters
Eignvalues: 1 = +0.02059 2 = +0.02201 3 = +0.01433

Principal Axis Matrix

+0.82900	+0.00000	+0.55920
+0.00000	+1.00000	+0.00000
-0.55920	+0.00000	+0.82900

Moment of inertia matrix in A.C.S.

+0.018631	+0.000000	+0.002902
+0.000000	+0.022010	+0.000000
+0.002902	+0.000000	+0.016287

*** Minus X Sled Runs ***

	10 G-Level Run LX3993		13 G-Level Run LX3961		14 G-Level Run LX3968		15 G-Level Run LX3983	
	Max	Min	Max	Min	Max	Min	Max	Min
Force X-Axis	28.56	-629.12	81.13	-969.39	92.79	-961.99	100.82	-994.27
Force Y-Axis	20.05	-42.76	30.54	-84.36	57.22	-119.35	67.90	-89.18
Force Z-Axis	46.41	-418.24	41.61	-739.49	43.32	-826.82	42.62	-769.25
Force Result	722.41	14.38	1089.09	+11.57	1114.39	13.86	1182.19	10.44

	10 G-Level Run LX3993		13 G-Level Run LX3961		14 G-Level Run LX3968		15 G-Level Run LX3983	
	Max	Min	Max	Min	Max	Min	Max	Min
Torque X-Axis	3.77	-1.98	5.67	-1.91	7.27	-5.35	7.75	-3.02
Torque Y-Axis	2.06	-39.14	7.09	-47.83	10.04	-53.65	9.23	-55.22
Torque Z-Axis	0.63	-0.68	1.50	-2.65	2.39	-4.18	1.05	-1.71
Torque Result	39.25	+0.05	47.99	+0.05	53.72	+0.02	55.76	0.15

	10 G-Level Run LX3993		13 G-Level Run LX3961		14 G-Level Run LX3968		15 G-Level Run LX3983	
	HIC Nbr	Width	HIC Nbr	Width	HIC Nbr	Width	HIC Nbr	Width
HIC X-Axis	46.27	80.00	96.30	67.50	93.33	67.00	137.66	71.50
HIC Y-Axis	0.08	89.00	0.64	200.50	0.11	121.00	0.22	175.00
HIC Z-Axis	10.54	65.00	18.36	54.50	25.43	49.50	25.01	43.00
Resultant HIC	66.03	103.00	127.56	89.00	134.16	87.00	186.80	84.00

SUBJECT H00134

*** Plus Y Sled Runs ***

	5 G-Level Run LX4097 Max	Min	6 G-Level Run LX4112 Max	Min	7 G-Level Run LX4126 Max	Min
Force X-Axis	20.59	-171.14	31.85	-243.86	60.02	-262.26
Force Y-Axis	330.00	-42.60	366.24	-67.13	399.14	-87.26
Force Z-Axis	43.97	-162.33	52.70	-250.91	47.34	-307.52
Force Result	374.40	16.35	422.86	31.73	489.36	41.01

	5 G-Level Run LX4097 Max	Min	6 G-Level Run LX4112 Max	Min	7 G-Level Run LX4126 Max	Min
Torque X-Axis	2.77	-24.35	5.53	-31.37	6.92	-31.04
Torque Y-Axis	2.25	-10.17	4.14	-14.51	8.02	-14.86
Torque Z-Axis	7.90	-0.25	10.94	-2.23	10.66	-2.81
Torque Result	26.57	+0.34	33.02	+0.45	34.45	+0.04

	5 G-Level Run LX4097 HIC Nbr	Width	6 G-Level Run LX4112 HIC Nbr	Width	7 G-Level Run LX4126 HIC Nbr	Width
HIC X-Axis	11.15	114.50	13.69	103.50	16.27	86.50
HIC Y-Axis	0.08	133.00	0.06	143.50	0.21	112.00
HIC Z-Axis	1.14	70.00	0.98	69.50	2.08	55.00
Resultant HIC	13.70	116.50	15.89	105.50	20.62	91.00

*** Minus X / Plus Y ***

	9 G-Level Run LX4264 Max	Min	10 G-Level Run LX4298 Max	Min	11 G-Level Run LX4307 Max	Min
Force X-Axis	30.28	-520.00	37.18	-589.15	43.68	-680.55
Force Y-Axis	356.98	-48.65	341.57	-49.29	361.52	-86.75
Force Z-Axis	42.31	-337.14	43.75	-473.28	42.29	-631.21
Force Result	681.84	25.56	755.83	+14.07	924.77	12.78

	9 G-Level Run LX4264 Max	Min	10 G-Level Run LX4298 Max	Min	11 G-Level Run LX4307 Max	Min
Torque X-Axis	4.33	-28.12	3.69	-23.99	6.58	-29.66
Torque Y-Axis	2.47	-32.52	3.15	-36.92	3.69	-42.53
Torque Z-Axis	10.54	-0.90	10.82	-1.49	12.12	-0.88
Torque Result	41.17	+0.06	42.17	+0.17	48.55	+0.03

	9 G-Level Run LX4264 HIC Nbr	Width	10 G-Level Run LX4298 HIC Nbr	Width	11 G-Level Run LX4307 HIC Nbr	Width
HIC X-Axis	40.91	82.50	45.56	74.50	70.22	75.00
HIC Y-Axis	0.35	188.00	0.23	142.00	0.66	196.00
HIC Z-Axis	5.30	114.00	8.85	63.00	12.53	105.50
Resultant HIC	54.40	107.00	62.68	102.00	96.89	87.00

SUBJECT H00135

*** Head Anatomical Configuration ***

Head Mass : 3.791 Kg.
Head Center of Gravity: X = +0.0080 Y = -0.0005 Z = +0.0300 Meters
Head / Neck Center of Gravity: X = +0.0190 Y = +0.0000 Z = +0.5800 Meters
Eignvalues: 1 = +0.01683 2 = +0.01800 3 = +0.01171

Principal Axis Matrix

+0.82900	+0.00000	+0.55920
+0.00000	+1.00000	+0.00000
-0.55920	+0.00000	+0.82900

Moment of inertia matrix in A.C.S.

+0.015228	+0.000000	+0.002374
+0.000000	+0.018000	+0.000000
+0.002374	+0.000000	+0.013310

*** Minus X Sled Runs ***

	10 G-Level Run LX3916		13 G-Level Run LX3955		14 G-Level Run LX3965		15 G-Level Run LX3970	
	Max	Min	Max	Min	Max	Min	Max	Min
Force X-Axis	80.70	-632.31	122.75	-786.30	114.80	-1078.20	91.83	-840.30
Force Y-Axis	36.37	-109.08	25.83	-120.50	44.89	-141.20	16.60	-210.44
Force Z-Axis	71.48	-360.26	114.49	-559.82	192.81	-764.17	36.55	-675.56
Force Result	717.10	6.56	891.40	10.25	1294.03	11.38	955.28	9.40

	10 G-Level Run LX3916		13 G-Level Run LX3955		14 G-Level Run LX3965		15 G-Level Run LX3970	
	Max	Min	Max	Min	Max	Min	Max	Min
Torque X-Axis	8.27	-2.39	9.50	-2.26	9.68	-5.45	18.09	-1.70
Torque Y-Axis	5.41	-33.14	7.63	-44.79	8.78	-68.54	8.68	-49.17
Torque Z-Axis	0.94	-1.29	2.52	-2.94	3.68	-3.70	2.05	-4.10
Torque Result	33.21	0.13	44.82	0.24	68.58	0.17	49.35	0.27

	10 G-Level Run LX3916		13 G-Level Run LX3955		14 G-Level Run LX3965		15 G-Level Run LX3970	
	HIC Nbr	Width	HIC Nbr	Width	HIC Nbr	Width	HIC Nbr	Width
HIC X-Axis	50.13	85.50	90.27	75.50	116.77	74.00	109.17	75.50
HIC Y-Axis	0.08	38.50	0.06	200.00	0.24	207.00	0.06	229.00
HIC Z-Axis	9.27	137.00	16.62	49.50	23.61	108.50	24.95	45.00
Resultant HIC	66.22	107.50	120.46	87.50	162.35	84.00	154.17	86 .50

SUBJECT H00135

*** Plus Y Sled Runs ***

	5 G-Level		6 G-Level		7 G-Level	
	Run LX4095		Run LX4114		Run LX4131	
	Max	Min	Max	Min	Max	Min
Force X-Axis	31.37	-144.94	30.70	-204.51	52.96	-254.57
Force Y-Axis	286.25	-61.93	329.41	-91.10	365.60	-120.51
Force Z-Axis	54.27	-140.82	63.02	-224.09	76.10	-275.73
Force Result	325.10	30.09	375.44	32.69	447.19	36.17

	5 G-Level		6 G-Level		7 G-Level	
	Run LX4095		Run LX4114		Run LX4131	
	Max	Min	Max	Min	Max	Min
Torque X-Axis	5.34	-21.65	6.21	-23.75	8.84	-28.43
Torque Y-Axis	3.07	-8.76	3.55	-9.52	7.36	-12.95
Torque Z-Axis	7.75	-1.17	7.91	-1.94	10.66	-3.03
Torque Result	23.96	0.23	26.48	0.27	32.92	0.33

	5 G-Level		6 G-Level		7 G-Level	
	Run LX4095		Run LX4114		Run LX4131	
	HIC Nbr	Width	HIC Nbr	Width	HIC Nbr	Width
HIC X-Axis	11.42	117.00	14.85	102.50	40.85	81.00
HIC Y-Axis	0.13	151.50	0.15	141.50	0.32	131.50
HIC Z-Axis	0.89	74.00	1.30	48.50	3.88	54.50
Resultant HIC	13.77	121.00	18.28	102.00	50.76	101.00

*** Minus X / Plus Y ***

	9 G-Level		10 G-Level	
	Run LX4314		Run LX4316	
	Max	Min	Max	Min
Force X-Axis	.	.	.	.
Force Y-Axis	.	.	.	.
Force Z-Axis	.	.	.	.
Force Result	.	.	.	.

	9 G-Level		10 G-Level	
	Run LX4314		Run LX4316	
	Max	Min	Max	Min
Torque X-Axis	.	.	.	.
Torque Y-Axis	.	.	.	.
Torque Z-Axis	.	.	.	.
Torque Result	.	.	.	.

	9 G-Level		10 G-Level	
	Run LX4314		Run LX4316	
	HIC Nbr	Width	HIC Nbr	Width
HIC X-Axis	40.85	81.00	51.32	79.00
HIC Y-Axis	0.32	131.00	0.37	162.00
HIC Z-Axis	3.88	54.50	6.10	55.50
Resultant HIC	50.76	101.50	63.92	94.00

SUBJECT H00136

*** Head Anatomical Configuration ***

Head Mass : 4.235 Kg.
Head Center of Gravity: X = +0.0083 Y = -0.0005 Z = +0.0312 Meters
Head / Neck Center of Gravity: X = +0.0190 Y = +0.0000 Z = +0.5800 Meters
Eignvalues: 1 = +0.02024 2 = +0.02164 3 = +0.01409

Principal Axis Matrix		
+0.82900	+0.00000	+0.55920
+0.00000	+1.00000	+0.00000
-0.55920	+0.00000	+0.82900

Moment of inertia matrix in A.C.S.		
+0.018316	+0.000000	+0.002851
+0.000000	+0.021640	+0.000000
+0.002851	+0.000000	+0.016012

*** Minus X Sled Runs ***

	10 G-Level Run LX3918		12 G-Level Run LX3942		13 G-Level Run LX3953		14 G-Level Run LX3962	
	Max	Min	Max	Min	Max	Min	Max	Min
Force X-Axis	.	.	.	.	.	.	.	.
Force Y-Axis	.	.	.	.	.	.	.	.
Force Z-Axis	.	.	.	.	.	.	.	.
Force Result	.	.	.	.	.	.	.	.

	10 G-Level Run LX3918		12 G-Level Run LX3942		13 G-Level Run LX3953		14 G-Level Run LX3962	
	Max	Min	Max	Min	Max	Min	Max	Min
Torque X-Axis	.	.	.	.	.	.	.	.
Torque Y-Axis	.	.	.	.	.	.	.	.
Torque Z-Axis	.	.	.	.	.	.	.	.
Torque Result	.	.	.	.	.	.	.	.

	10 G-Level Run LX3918		12 G-Level Run LX3942		13 G-Level Run LX3953		14 G-Level Run LX3962	
	HIC Nbr	Width	HIC Nbr	Width	HIC Nbr	Width	HIC Nbr	Width
HIC X-Axis	48.48	91.50	65.83	92.50	85.96	83.50	99.13	85.50
HIC Y-Axis	0.08	528.50	0.18	189.50	0.18	194.00	0.09	84.00
HIC Z-Axis	8.95	61.00	16.22	53.50	19.11	52.00	14.07	120.00
Resultant HIC	65.84	107.50	95.49	95.50	121.16	100.00	128.32	85.50

SUBJECT H00136

*** Plus Y Sled Runs ***

	5 G-Level Run LX4098		6 G-Level Run LX4142		7 G-Level Run LX4153	
	Max	Min	Max	Min	Max	Min
HIC X-Axis	9.42	118.00	13.37	100.00	18.48	82.00
HIC Y-Axis	0.17	188.50	0.36	154.50	0.53	127.50
HIC Z-Axis	0.77	77.50	1.28	119.00	2.64	106.50
Resultant HIC	11.57	124.00	16.91	104.50	24.36	90.00

*** Minus X / Plus Y ***

	7 G-Level Run LX4247		9 G-Level Run LX4263	
	HIC Nbr	Width	HIC Nbr	Width
HIC X-Axis	23.27	115.00	33.30	81.50
HIC Y-Axis	0.14	59.50	0.61	57.00
HIC Z-Axis	1.94	58.00	6.11	63.00
Resultant HIC	27.86	112.00	47.72	109.50

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The Naval Biodynamics Laboratory has collected a data base describing the head/neck kinematic response of a large number of human subject volunteers to -X, +Y, and -X+Y vector exposures. This publication will present injury-related parameters for the most severe exposures in each vector, together with correlations of these parameters with the medical findings.

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